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Inclusion of the Heating Sector in the EU Emissions Trading System

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Abstract

European Union has committed itself to an ambitious target for reducing its greenhouse gas emissions by 80-95 % until 2050. The commitment has milestones of which the one set for 2020 will be achieved; however, the targets set for 2030 and 2050 will not be reached with existing policies. The heating sector the second biggest source of emissions after transportation which has been excluded from the emission trading system. Inclusion of the heating sector in the EU emissions trading system provides a prospective alternative for reforming the European climate policy in accordance with the upcoming reduction targets.

The scope of the thesis was to research and study the European heating sector and evaluate the effects of its possible inclusion in the emissions trading system. Majority of the heating which is not covered by emissions trading consists of small, property-specific gas and oil boilers which together produce some 15 % of Europe's overall emissions. These emissions could be reduced by energy efficiency measures and the latest recast of the energy efficiency directive has indeed achieved significant reductions within new constructions. However, old building stock coupled with slow renovation rate means that the current trend is not sufficient to meet the future emissions targets.

Efficiency improvements to the building stock provide the largest potential of cost-effective emission reductions. Large share of this potential is not only cost-effective but also cost-negative which means that certain reduction measures also save money. The cost-negative potential has been focused in particular to the residential sector which often fails to recognize the long-term viability beyond excessive upfront payments. Current policies distinguish the heating sector from the emissions trading meaning that emissions trading sectors have no incentive to carry out reduction measures in the heating sector, despite these measures would be cheaper compared to the ones currently being implemented.

Large number property-specific of gas and oil boilers means that the existing downstream regulations would not be feasible and the obligation to comply should be directed upstream to the fuel supplier level. California Cap-And-Trade Program is an example of such system, having succeeded in the implementation of a mixed downstream and upstream regulation.

Keywords Emission Trading, Heating Sector, Energy and Climate Policy

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Tiivistelmä

Euroopan Unioni on asettanut itselleen kunnianhimoisen tavoitteen vähentää kasvihuonepäästöjään 80-95 % vuoteen 2050 mennessä. Sitoumuksella on välitavoitteita, joista vuoden 2020 vähennystavoitteet tullaan saavuttamaan. Asetetut tavoitteet vuosille 2030 sekä 2050 jäävät nykypolitiikalla kuitenkin saavuttamatta. Lämmityssektori on liikenteen jälkeen suurin päästökaupan ulkopuolelle rajattu päästöjenlähde. Yksi mahdollinen vaihtoehto uudistaa eurooppalaista ilmastopolitiikkaa tulevien vähennystavoitteiden mukaiseksi olisi sisällyttää lämmityssektori kokonaisuudessaan Euroopan Unionin päästökauppajärjestelmään.

Työssä tarkasteltiin Euroopan lämmityssektoria ja arvioitiin, mitä vaikutuksia sektorin liittämisellä päästökauppaan saattaisi olla. Päästökaupan ulkopuolinen lämmityssektori koostuu pitkälti pienistä ja kiinteistökohtaisista kaasu- ja öljykattiloista, jotka aiheuttavat noin 15 % Euroopan kokonaispäästöistä. Lämmityssektorin päästöjä voitaisiin alentaa huomattavasti erinäisillä energiatehokkuustoimilla ja viimeisimmät päivitykset energiatehokkuusdirektiiviin ovatkin onnistuneet parantamaan uusimpien rakennusten energiatehokkuutta huomattavasti. Vanha rakennuskanta yhdistettynä hitaaseen remontointitahtiin tarkoittaa kuitenkin, ettei päästöjen nykyinen vähenemistahti ole riittävä.

Rakennuskannan energiatehokkuustoimet ovat huomattavasti kustannustehokkaampi päästövähennyskeino verrattuna muihin sektoreihin. Suuri osa vähennyspotentiaalista ei ole pelkästään kustannustehokasta, vaan myös kustannusnegatiivista tarkoittaen, että tietyt päästövähennystoimet säästävät myös rahaa. Kustannusnegatiivinen potentiaali on keskittynyt erityisesti asuinrakennuksiin, joiden omistajat eivät aina tunnista suurten investointikustannusten takana olevaa pitkän tähtäimen kannattavuutta. Nykysysteemi erottelee lämmityssektorin päästökaupasta, jolloin päästökauppasektorilla ei ole kannustimia osallistua lämmityssektorin vähennystoimiin nykyisten, huomattavasti kalliimpien vähennystoimien sijasta.

Kiinteistökohtaisten kaasu- ja öljypolttimien suuri määrä tarkoittaa, että nykyinen päästölähdeperusteinen valvontatapa ei olisi järkevää, vaan päästöjen tarkkailu- ja raportointivelvollisuus tulisi osoittaa ylävirtaan polttoainetoimittajille. Kalifornian päästökauppajärjestelmä on esimerkki järjestelmästä, jossa jo nykyisellään toteutetaan onnistuneesti sekaisin ylä- ja alavirtaraportointia.

Avainsanat Päästökauppa, Lämmityssektori, Ilmasto- ja energiapolitiikka

Foreword

This Master's thesis has been written between July 2018 and February 2019 while working for the Finnish Energy. I would like to show my gratefulness to Finnish Energy for the opportunity to write a thesis on such an interesting and timely topic. The topic was chosen in spring 2018 due to its topicality after several valuable conversations with the colleagues. The scope of the thesis was to study the inclusion of the heating sector in the European Union emission trading system.

I would like to thank my thesis advisor Jukka Makkonen for our fruitful discussions and for all the guidance. I would also like to thank my thesis supervisor Sanna Syri for the invaluable instructions. Great thanks also belong to the employees of Finnish Energy for all the small tips I received during the project.

Furthermore, I would like to thank all the people I met during my studies. Otaniemi and its community have certainly provided me countless of memories, adventures and new friends that will all remain despite my years of studying are coming to the end.

Otaniemi 17.2.2019

Joonatan Huhdanmäki

Contents

Abbreviations

AAU	Assigned Amount Unit
AER	Annual Emissions Report
BR	Biennial Report
BUR	Biennial Update Report
CARB	California Air Resources Board
CDM	Clean Development Mechanism
COP	Conference of Parties
DOE	Designated Operational Entities
EB	Executive Board
EC	European Commission
EEX	European Energy Exchange
ETS	Emission Trading System
EU	European Union
EUA	European Union Allowance
EU ETS	European Union Emission Trading System
EUTL	European Union Transaction Log
GDP	Gross Domestic Product
GWP	Global Warming Potential
ICE	Intercontinental Exchange Futures Europe
IEs	Independent Entities
IET	International Emissions Trading
IPCC	Intergovernmental Panel on Climate Change
ITL	International Transaction Log
JI	Joint Implementation
LDC	Least Developed Countries
LULUCF	Land use, land-use change and forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MRV	Monitoring, Reporting and Verification
MSR	Market Stability Reserve
NAP	National Allocation Plan
NIM	National Implementation Measures
OECD	Organisation for Economic Co-operation and Development
PCC	Pearson Correlation Coefficient
PPP	Purchasing Power Parity
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization

1 Introduction

The European Union has committed itself to reduce its greenhouse gas (GHG) emissions by at least 80 % until 2050 compared to the 1990 levels (Babonneau, et al., 2018). These reduction targets are addressed in a variety of ways such as traditional regulation, taxation of fuels and emission trading. Emissions from large stationary industrial installations as well as most of the energy activities are being governed by Emission Trading System (ETS). Emissions not covered by the ETS are regulated by the so-called effort sharing decision which imposes differentiated reduction targets for the remaining sectors. Emissions covered by the ETS face more stringent targets as this sector is expected to provide more potential for cost-effective reductions. (European Commission, 2015)

European Union Emission Trading System (EU ETS) was created in a wake of adopting the Kyoto protocol in 1997 – the first international agreement with binding targets on GHG emissions (Nykänen, et al., 2006). The system commenced in 2005 and is based on tradable emission permits which companies must surrender an amount equivalent to their GHG emissions. Tradability of permits aims to direct the required mitigation measures to point sources with lowest reduction costs, causing as little economic harm as possible. Launching the system was characterized by uncertainties as there was no conception nor practical expertise on such system. Due to the lack of experience and shortage of information on the required instruments, the system was planned to be gradually improved and expanded step-by-step as more experience is accumulated. (Ellerman, et al., 2010)

As of January 2019, the system has been under operation for 14 years. The first three years was considered a learning period wherein the monitoring infrastructure was created and practical experience was gained. This was followed by the second period with binding Kyoto targets from 2008 to 2012. The third period runs from 2013 to 2020 and the fourth period during 2021-2030. Throughout the years of operation the system has faced several challenges and gone through various structural changes, related in particular to the lower-than-expected price of emission allowances. Repairing these structural weaknesses has distracted attention from the initial vision of gradual expansion of the system. (Borghesi & Flori, 2018) Despite minor expansions have been implemented, the share of GHG emissions currently covered by the EU ETS is lower than in 2005 when the system was commenced (European Environment Agency, 2019a; European Environment Agency, 2019b).

Building sector is the second-most emitting sector not covered by the ETS and it is estimated to provide the greatest untapped potential of cost-effective emission reductions (European Council, 2018; Forster, et al., 2012). By far the largest share of these emissions are caused by burning of natural gas and oil in small on-site decentralized boilers (Heat Roadmap Europe, 2017). As opposed to the transportation – the largest single emitting sector not covered by the EU ETS – taxation of heating fuels is rather heterogeneous between member states of the European Union (European Commission, 2019). According to the emission trading fundamentals, significant differences in fuel taxation will increase the overall cost of emission reductions (Yamin, 2005). Given the considerations above, it is evident that building sector provides a potential alternative to be included in the European Union Emission Trading System.

California Cap-and-Trade Program is another emission trading system launched in 2013. The main characteristics of the system are similar to EU ETS, making their comparison conceivable. The Californian scheme is a point of interest in particular with regards to the inclusion of the heating sector in the EU ETS as the sector has already been included in emission trading. As opposed to the EU ETS characterized by pure downstream regulation, Californian system implements mixed regulation wherein the obligation to comply is directed upstream to the fuel distributors within the transportation and heating sectors. (California Air Resources Board, 2019a)

1.1 Research Objectives

The first research objective of this thesis is to study entities and concepts related to the inclusion of the heating sector in the EU ETS. Small property-specific gas and oil boilers in residential and service sector buildings are of particular interest as they produce by far most of the GHG emissions in the building sector. Both the energy consumption as well as the boiler units themselves are analyzed and countries for which this heating method is especially important are identified. Taxation is currently the predominant means of control for the non-ETS heating. Thus, the existing fuel taxation in the EU is studied and taxation levels of natural gas and oil are aggregated to tables.

The second research objective is to briefly study other existing emission trading systems worldwide and identify examples of systems in which the heating sector has already been included. Successful inclusion in another ETS with similar characteristics to the EU ETS would provide information and valuable lessons to the European system. The main focus is to review how monitoring, reporting and verification process is carried out for a sector which will require upstream solution.

This thesis will contribute to the ongoing discussion on the inclusion of the heating sector in the EU ETS and provide further insights compared to the previous reports on the same topic, such as (GreenStream, 2015), in a form of more detailed analysis on the non-ETS heating sector. Prior the data release by (Heat Roadmap Europe, 2017) there was no such opportunity as comprehensive heating data did not exist. Another new contribution on the topic is the comparison of the California Cap-and-Trade Program to the European equivalent.

1.2 Structure and boundaries of the Thesis

The literature section of this thesis consists of chapters 2 and 3. Chapter 4 includes a thorough data analysis on the European heating sector and chapter 5 strives to learn lessons from other emission trading systems for possible inclusion of the heating sector in the EU emissions trading system.

Chapter 2 focuses on the background and history of the international climate policy. It tells the story of how climate policy was born in the 1970s as well as describes the mechanisms and tools being used to implement these policies.

Chapter 3 describes the development of the European Union Emission Trading System since its commence until today. The system has gone through several structural modifications which are presented along with the current operating principles. Additionally, the effectiveness of the system is briefly evaluated.

Chapter 4 includes a data analysis on the European heating sector, focusing in particular on that part of the heating which is not already included in emission trading. In addition to the energy use, also the building and boiler stocks are analyzed as all of these features play an important role in the heating sector. Moreover, as taxation is currently the principle means of control for heating fuels, a comparison of fuel taxation between countries is carried out.

Chapter 5 briefly studies other existing emission trading systems and strives to identify possible examples of systems in which the heating sector has been successfully included in emission trading.

As of February 2019 the final outcome of the decision by the United Kingdom to withdraw from the European Union is unclear. The possible impact of the withdrawal to the EU ETS is not speculated and United Kingdom is treated as if it would continue to participate emission trading as before. Neither the climate change science nor the legislative process required to the inclusion are studied in this thesis.

2 The Birth of International Climate Policy

During the 1970s, a consensus among the scientific world on anthropogenic climate change began to build up. The greenhouse effect had been recognized far before this but human impact on climate system had remained debatable. Competitive explanations for the changing climate included variations in the Earth's orbit and in the number of sunspots. There were also discussions about the potential cooling effect from the particulate pollution. It was not before the late 1980s when first concrete measures were taken towards alleviating the climate change. Since then the research as well as the methods for mitigating the effects have taken notable steps forward. (Yamin, 2005)

Intergovernmental Panel on Climate Change (IPCC) was established in 1988 in order to evaluate the research on climate change and to produce easily understandable information for policy makers. It was soon followed by first international agreements aiming to reduce the GHG emissions. This chapter presents a brief history of the international climate policy beginning from the 1970s and finishing to the ratification of the Kyoto Protocol. The protocol entered into force in 2008 and it did not only impose stiff country-specific targets but also enabled parties to utilize various types of market-based flexibility mechanisms. These flexibility mechanisms allowed parties to trade emission allowances like any other commodity and created what is today known as a carbon market. (Valtonen, 2013)

2.1 United Nations Framework Convention on Climate Change

The kick-start of the international climate policy can be traced back to Stockholm in 1972 when the UN Conference on the Human Environment was arranged. This conference was the first major conference focused on international environmental issues. The Resolution of this conference acknowledged the importance to safeguard the human environment as well as recognizes the need for collaboration between the countries in environmental issues. (United Nations, 1972; United Nations, 2019)

In the wake of the conference, United Nations Environment Programme (UNEP) was established and environment ministries began to pop-up across the globe. First solely climate-related conference was convened by World Meteorological Organization (WMO) in 1979 and was attended by hundreds of experts and scientists from various disciplines. The declaration of the conference agreed that it is urgently necessary for the nations of the world to advance and take steps to improve the present knowledge of climate as well as prevent potential man-made changes in climate. However, no precise targets on future emission levels were agreed on. (Nykänen, et al., 2006; World Meteorological Organization, 2009)

IPCC was established in 1988 by the UNEP and by the WMO. IPCC is considered the world's leading authority on climate change. Its function is to comprehensively assess and review the most recent data relevant to the understanding of the climate change as well as compile information to an easily understandable form for policy-makers. Assessment reports are ICPP's most predominant publications and they are widely quoted on discussions regarding the climate change. These periodic reports are published in every 5-6 years, most recent being the Fifth Assessment Report released in 2014. (Nykänen, et al., 2006; The Royal Society, 2005; Intergovernmental Panel on Climate Change, 2018)

The First Assessment report by the IPCC was released in 1990 and it acted as a foundation for the United Nations Framework Convention on Climate Change (UNFCCC) adopted in

1992. Negotiations towards the convention turned out to be arduous as the visions among the countries collided heavily. Developing countries emphasized their right for economic development and underlined the responsibility of the industrialized countries. Oil producers were keen on protecting their revenues whilst small island states raised their concerns about rising sea levels. According to the USA developed countries should take the lead not because of the historical anthropogenic emission but because of their better technological ability. Consequently, the outcomes of the UNFCCC remained loose as perspectives among the countries were simply too high. (Nykänen, et al., 2006; Valtonen, 2013)

The ultimate objective of the convention was to stabilize the atmospheric GHG concentrations at a level that prevents dangerous anthropogenic interference with the climate system. This ought to be achieved so that neither food production nor sustainable economic development is threatened. The convention recognizes that interference with the climate system cannot be completely averted and certain level of adaption by the ecosystems will be needed. The time frame of this change should be sufficiently long so that the adaption can take place naturally. (United Nations, 1992)

The convention did manage to agree on the concept of common but differentiated responsibility. This means that the parties were divided into three main categories with different commitment levels. Original annex I parties consisted of the 24 founding countries of the Organisation for Economic Co-operation and Development (OECD), The European Union and countries with Economies In Transition (EIT), the latter group consisting of countries from Central and Eastern Europe. OECD countries and the EU also belong to annex II of the convention. Non-annex I parties include all the remaining countries. This group is largely made of developing countries and it has two subcategories: one for countries especially vulnerable to the adverse effects of climate change and another one for the Least Developed Countries (LDC) with limited resources and capacities to respond to climate change. (United Nations, 1992; United Nations, 2018a) The parties listed in annex I and annex II of the UNFCCC are presented below in Table 1. The table describes the situation as of September 2018 and differs slightly from the original document as certain countries have been added and removed from the annexes.

Table 1 Annex I and annex II parties of the Convention with differentiated responsibilities (United Nations, 2018b).

Annex I & Annex II				Only Annex I		
Australia	Austria	Belgium	Canada	Belarus	Bulgaria	Croatia
Denmark	The EU	Finland	Germany	Cyprus	Czech Republic	Estonia
France	Greece	Iceland	Italy	Hungary	Latvia	Liechtenstein
Ireland	Japan	Luxembourg	New Zealand	Lithuania	Malta	Monaco
Netherlands	Japan	Portugal	Spain	Poland	Romania	Russian Federation
Sweden	Switzerland	United Kingdom	United States	Slovakia	Slovenia	Turkey
				Ukraine		

The convention determines that all parties must collect relevant information of their anthropogenic GHGs and based on this establish national inventories by sources and removals by sinks. These inventories must be updated periodically and made available for the public. Developed countries must provide technological and financial support for developing countries so that they can prepare these inventories. National programmes towards climate change mitigation shall be initiated by all parties together with promotion towards conservation and enhancement of all sinks and reservoirs, including biomass, forests, oceans and ecosystems. (United Nations, 1992; Yamin, 2005)

The convention states that annex I countries should take the lead in international climate policy. The publication cycle of the GHG inventories is stricter for this group as they must be prepared annually. (Yamin, 2005) Annex II parties are also required to provide financial support to the EIT parties and to developing countries as well as promote environmentally friendly technologies. (United Nations, 2018a)

According to the UNFCCC, annex I countries were required to freeze their annual GHG emissions to the 1990 levels by the end of the millennium (United Nations, 1992). Although these targets were legally non-binding, annex I parties as a whole met the target levels easily as GHG emissions decreased by 12 % from 1990 to 2000. Looking in more detail, the emissions of annex I non-EIT increased by 9 % while they decreased by 51 % in EIT countries due to the economic regression caused by the fall of the Soviet Union. (United Nations, 2018c) Proportional changes in annexes' overall GHG emissions including Land Use, Land-Use Change and Forestry (LULUCF) sector from 1990 to 2016 together with annex I parties' share of total global GHG emissions is presented below in Figure 1.

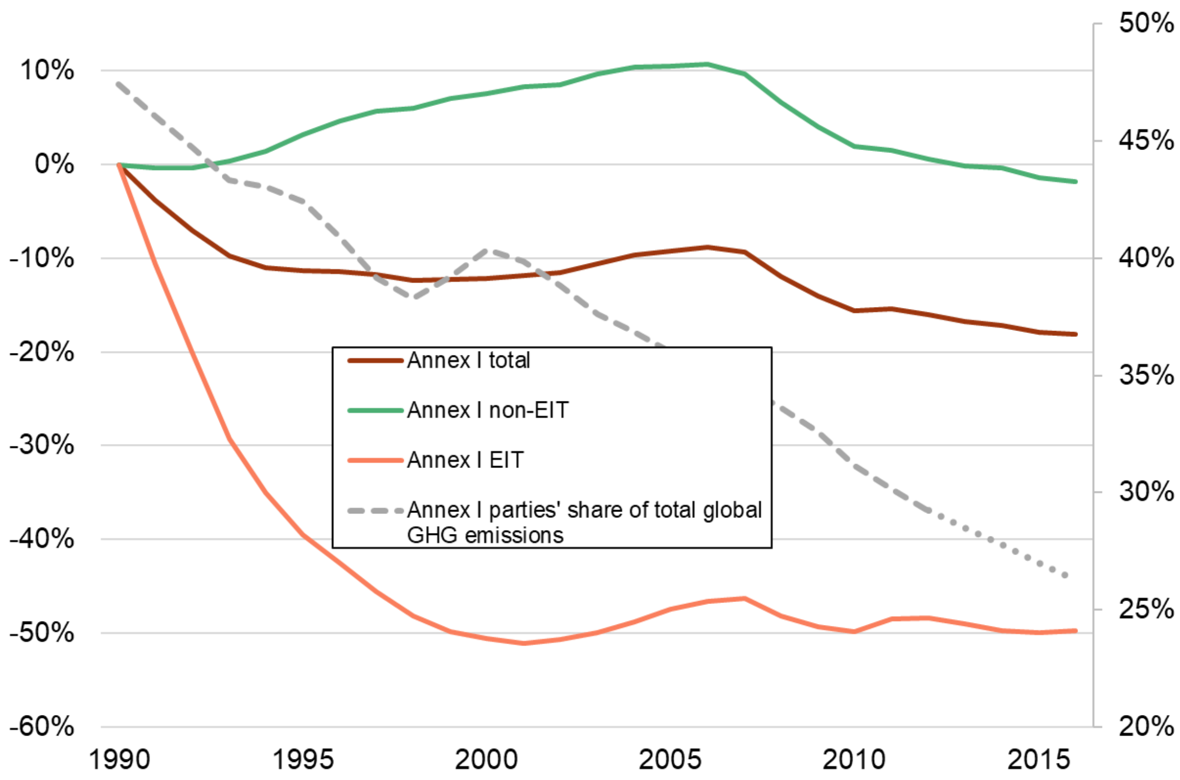

Figure 1 Proportional changes of annex I parties' total GHG emissions (left axis) and their share of global emissions (right axis) (United Nations, 2018c; World Bank, 2018a).

The figure shows a clear gradual trend of decreasing emission levels. However, annex I parties' significance towards the global GHG emissions has concurrently decreased significantly. While the group emitted approximately half of all the emissions in 1990, their contribution to the global emissions was only 29 % in 2012. Simultaneously, overall global emissions have been steadily increasing during the whole time period from 1990 onwards. (World Bank, 2018a)

The most important decision-making body of the UNFCCC is the annually held Conference Of Parties (COP) to which all parties of the convention participate in. In addition to decision-making, the COP also provides a forum for high-profile discussions. The COP is supported by a secretariat and two subsidiary bodies that meet more frequently and prepare the agenda for the COP's meetings. (Nykänen, et al., 2006)

Parties of the convention must submit national communications to the COP in every few years. Timetable and the level of detail is different between developing and developed country parties. National communications are detailed implementation reports, providing information on present and projected GHG emissions as well as policies and measures towards emission reductions and climate change mitigation actions. These reports are subject to throughout review by the experts. The monitoring process was further enhanced in 2014: developed countries are now also required to submit Biennial Reports (BRs) and developing countries Biennial Update Reports (BURs) in every two years. Together with the GHG inventories, national communications, BRs and BURs are cornerstones in the monitoring process of the convention. (United Nations, 2018d; Yamin, 2005)

2.2 Kyoto Protocol

After the UNFCCC had been adopted, parties of the convention began to prepare binding targets for annex I countries. These legally binding greenhouse gas emission targets were written down to the Kyoto Protocol – an independent part of the UNFCCC – adopted in third COP meeting in 1997. (Nykänen, et al., 2006) Annex B of the protocol defines quantified emission limits for all 43 annex I parties of the UNFCCC except for Turkey, Belarus, Cyprus and Malta. Overall GHG emissions of these countries should be at least 5 % below the base year during the commitment period from 2008 to 2012. The targets set for the EU were even more ambitious: majority of its members were committed to reduce their emissions by 8 % with small alleviations given for both Hungary and Poland. (United Nations, 1998) The protocol became effective in 2005 and as of December 2018 it has been ratified by 192 parties including all major emitters except for the United States. Canada withdrew from the protocol in 2011 and it is the only country to ever done so. (United Nations, 2018e; United Nations, 2018f)

The Protocol takes the six main greenhouse gases into consideration, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Sectors covered by the Protocol are provided in annex A of the Protocol and consists of fuel combustion and fugitive emissions from fuels in the energy industry, majority of energy-intensive industrial processes, activities related to agriculture as well as waste treatment and management. The use of LULUCF sector in calculations is limited to net changes in GHGs from direct human-induced land-use change and forestry activities. (United Nations, 1998; United Nations, 2008)

Parties listed in annex B are given a limit for their GHG emissions during the commitment period. This limit is given as a percentage compared to the emissions occurred during the base year. The assigned amount of allowed GHG emissions for each party during the five-year-long commitment period is equal to the percentage provided in annex B multiplied by five. (United Nations, 1998) The base year used in the calculations is 1990 for most parties while Bulgaria, Hungary, Poland, Romania and Slovenia were permitted to use an earlier base year because of the economical regression during the 1990. The quantity of the assigned amount is further subdivided into smaller units called Assigned Amount Units (AAUs), each unit representing a permission to emit one metric ton of CO_2 or other GHG listed in annex A with an equivalent potential to promote the climate change. This equivalent global warming potential (GWP) is henceforth referred as CO_2-eqv. Alternatively, AAUs are occasionally referred as Kyoto units or as credits. (United Nations, 2008)

Most parties of the protocol faced reduction targets with varying commitment levels while others were ordered to freeze or could even increase their GHG emissions compared to the base year. Assigned amounts for all 39 annex B parties are presented below in Table 2. (United Nations, 2008) The European Union later redistributed the reduction targets among the member states with a burden-sharing agreement so that the overall reductions within the EU remained the same (Marklund & Samakovlis, 2006). The burden-sharing agreement is discussed more thoroughly in chapter 3.1.

Table 2 Assigned amounts during the commitment period from 2008 to 2012 for all 39 annex B parties of the Kyoto Protocol. The numbers are given as a percentage compared to the base year which is 1990 for most countries except for Bulgaria, Hungary, Poland, Romania and Slovenia who were permitted to use an earlier base year (United Nations, 1998).

Australia	108	Greece	92	Norway	101
Austria	92	Hungary	94	Poland	94
Belgium	92	Iceland	110	Portugal	92
Bulgaria	92	Ireland	92	Romania	92
Canada	94	Italy	92	Russian Federation	100
Croatia	95	Japan	94	Slovakia	92
Czech Republic	92	Latvia	92	Slovenia	92
Denmark	92	Liechtenstein	92	Spain	92
Estonia	92	Lithuania	92	Sweden	92
European Community	92	Luxembourg	92	Switzerland	92
Finland	92	Monaco	92	Ukraine	100
France	92	Netherlands	92	United Kingdom of Great Britain and Northern Ireland	92
Germany	92	New Zealand	100	United States of America	93

Unlike the UNFCCC which requires all emissions and removals from LULUCF sector to be covered in calculations, the Kyoto Protocol restricts them to direct, human-induced afforestation, reforestation and deforestation. This restriction was made due to the concerns regarding the accuracy and technical feasibility of estimating the quantity of the emissions and removals. Accounting the emissions and removals from these activities is mandatory for annex B parties and each party may choose whether it wishes to account and report them annually or solely after the commitment period. Additionally, parties may voluntarily decide to account and report its emissions and removals from forest management, cropland management, grazing land management and revegetation. Additional emission allowances from LULUCF sector are called Removal Units (RMUs) and they will add up to the party's initial assigned amount. Possible net emissions from LULUCF sector are subtracted from party's initial assigned amount. The parties may also acquire additional AAUs with so-called Kyoto mechanisms. These mechanisms allow parties to carry out projects and trade Kyoto units over their borders. Kyoto mechanisms are further discussed in chapter 2.3. Furthermore, the protocol allows countries to group up together and redistribute their reduction targets set for them in the annex B. (United Nations, 2008)

The actual emissions of a party must not exceed its assigned amount during the commitment period. Before this comparison is made, the emissions and removals from certain LULUCF activities and from Kyoto all mechanisms are added and subtracted from the initial assigned amount. The protocol states that domestic actions should be the primarily tool to comply with the emission levels. (United Nations, 1998) Figure 2 presents the compliance system of the protocol. In this example a party has bought more Kyoto units than it has sold and its carbon sinks have increased during the commitment period.

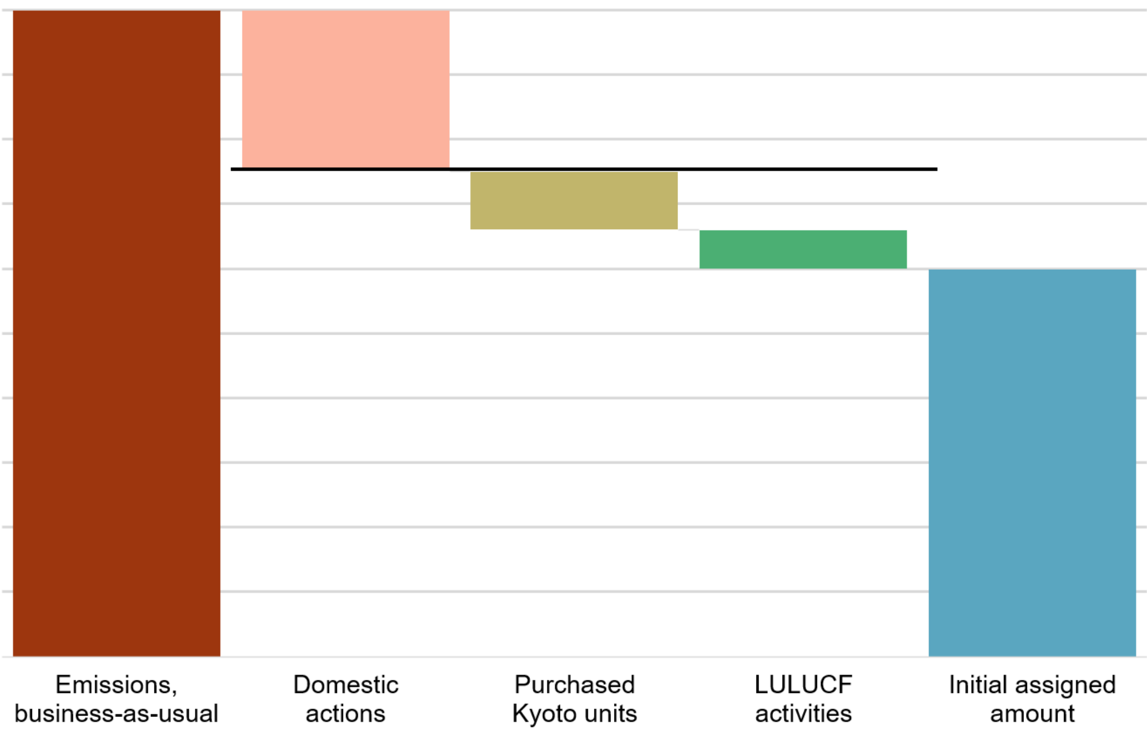

Figure 2 Compliance system of Kyoto Protocol explaining how domestic actions, Kyoto mechanisms and LULUCF are calculated towards the compliance

2.3 Flexibility Mechanisms in Kyoto Protocol

Kyoto mechanisms, also referred to as flexibility mechanisms, are market-based instruments defined by the protocol whose purpose is to provide cost-efficient emission reduction opportunities for annex B parties. The defining principle behind these mechanisms is that from the climate's point of view the location of the GHG source is irrelevant, thus best result is achieved when the resources are directed towards cheaper abatement costs. In addition to cost-effectiveness, the objective is to accelerate technology transfer from more developed countries to EIT countries and to developing countries. (Nykänen, et al., 2006)

There are three flexibility mechanisms defined by the protocol: Joint Implementation (JI), Clean Development Mechanism (CDM) and International Emissions Trading (IET). JI and CDM allow parties to carry out projects together while IET enables trading with AAUs from one party of the protocol to another. The protocol does emphasize; however, that these mechanisms should only serve as a supplementary method to domestic actions. The possibility for the parties to jointly fulfill their commitments – provided that their overall combined emission cap is not exceeded – can also be considered as one type of flexibility mechanism. (United Nations, 1998; Nykänen, et al., 2006)

Annex B parties have certain requirements that they must comply with before they can become eligible to participate in the Kyoto mechanisms. Following these requirements is voluntary but a non-compliance will result in as a disqualification from that given mechanism. Eligibility requirements include that the party must have ratified the Kyoto Protocol and created a national system for its GHG emissions and removals. The party must also have calculated its exact assigned amount in CO_2-eqv and established a national registry which follows the movement of Kyoto units. Furthermore, there are additional mechanism-specific eligibility requirements that are further discussed in chapters 2.3.1, 2.3.2 and 2.3.3 under each mechanism. (Haites & Yamin, 2004; United Nations, 2018g)

Parties may authorize their legal entities or stakeholders to participate in all of the Kyoto mechanisms, given that the party itself fulfills the eligibility requirements. Authorizing entities will enable a full realization of economic benefits as covering all GHG emission sources in every country sets a universal cost for emission reductions. Universal marginal abatement cost will, in theory, direct the reduction investments to where they are the cheapest and therefore minimizes the overall cost. Despite authorizing the stakeholders to carry out actions under the Protocol, the party itself remains responsible for the compliance of its obligations. (Haites & Yamin, 2004)

2.3.1 International Emissions Trading

Parties of the Kyoto Protocol have agreed to comply with their GHG emission targets defined in the annex B during the commitment period from 2008 to 2012. These targets are notified in assigned amounts which are divided into smaller units called assigned amount units (AAUs). Emissions trading allows parties with Kyoto commitments to acquire and sell AAUs with another party with Kyoto commitments. The objective is to address all mitigation measures so that the reduction of the next emission unit can be achieved with the lowest cost possible. This cost is called marginal abatement cost (MAC) and it is typically expressed as euros per emissions avoided. (Nykänen, et al., 2006)

As a market-based mechanism where the price of an AAU is determined by the supply and demand, International Emissions Trading (IET) creates a market for completely new commodity. The concept of trading the AAUs alongside with emission removal and reduction units is often referred as a "carbon market". AAUs and other Kyoto units acquired by CDM and JI projects are all valued equally, each unit allowing its owner to emit one ton of CO_2-eqv into the atmosphere. Although IET was originally designed to be implemented between the countries, national and regional emission trading schemes can be established by the parties in which legal entities operate under the governmental authorization. EU ETS is an example of such system, operating under the European Commission. (United Nations, 2018h)

Creating well-functioning emission trading scheme is not the main purpose itself. Contrarily, IET acts as an instrument given to the parties, striving to help them to achieve their commitments. This places a strong emphasis on concerns regarding the environmental integrity of the IET. Environmental integrity of emissions trading can be ensured with the presence of robust and transparent Monitoring, Reporting and Verification (MRV). Tracking systems such as national registries, institutional verification such as international transaction log as well as monitoring requirements such as the commitment period reserve altogether ensure the environmental integrity of IET. (Yamin, 2005)

The possibility to trade Kyoto units on emerging carbon markets generated a demand for a reliable tracking system. Since Kyoto units are intangible assets, registry systems must follow their locations at all times. All annex B parties have implemented such national registries while the UNFCCC secretariat is responsible of issuing and distributing credits earned by CDM projects. Each government or legal entity that wishes to participate in IET must have an account in one of the registry systems and all transactions between the governments and legal entities are carried out through these registries. The registries are connected by the International Transaction Log (ITL) whose purpose is to verify the proposed transactions in real time and to ensure the compliance with the protocol. The EU ETS has its own supplementary transaction log called the European Union Transaction Log (EUTL) which communicates with the ITL and ensures that the transactions also comply with the rules of the EU ETS. (United Nations, 2018i; United Nations, 2018j) Figure 3 presents the data exchange in the verification process of the transactions.

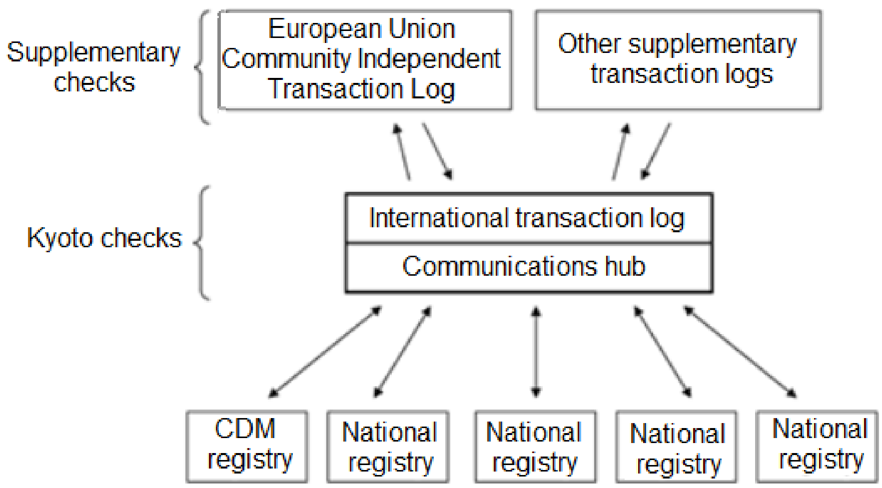

Figure 3 Data exchange during the verification process of Kyoto unit transactions (United Nations, 2018j). Modified by the author.

Selling Kyoto units can be profitable business for the parties which suggests that the risk of overselling is genuine existing. Overselling might be inadvertent or take place deliberately if a party decides to ignore the consequences of non-compliance. To address the concerns regarding the overselling – without hindering the efficiency and market liquidity of the IET – Commitment Period Reserve (CPR) was implemented by the UNFCCC. CPR determines the quantity of AAUs that a party must always keep in its national registry. The reserve must not fall below 90 % of party's assigned amount or below its most recently reviewed GHG inventory multiplied by five. Of these two options, the lower condition determines the required level of holdings. Adjustments can be made to the CPR during the commitment period as new information such as updated GHG inventories is taken into consideration. Although the CPR cannot entirely abolish the risk of overselling, it manages to prevent the theoretical worst-case scenario in which parties maximize their revenues, disregarding the resulting non-compliance. (OECD & IEA, 2001)

2.3.2 Clean Development Mechanism

The clean development mechanism is another flexibility mechanism defined in the Kyoto Protocol, aiming to provide cost-efficient emission reduction opportunities for annex B parties. This mechanism allows parties with Kyoto commitments or legal entities authorized by the parties to carry out emission reduction, afforestation and reforestation projects with non-annex B parties in which the MACs are typically lower. These projects are carried out in non-annex party countries and the resulting emission reductions earn Certified Emission Reductions (CERs) for the annex B party, each one valued as one ton of CO_2-eqv. Distinct from the IET wherein the overall number of AAUs remains the same, CDM projects create additional credits into the system. This highlights the need for a system capable to screen out those projects that would happen anyway – even without the additional funding by the CDM. (Yamin, 2005)

Parties in quest of CERs are subject to follow the CDM project cycle determined by the protocol and its modalities. The project cycle consists of five steps, two of which should be completed before the project has commenced and the remaining three while the project is running or once it has finished. First step requires the project participants to prepare a project design document which describes the project in question as well as technical details such as the continuance of the project and the baseline methodology. The document must also contain calculations on estimated emission reductions and a plan to oversee the project. Additionally, the document should contain comments from the stakeholders, information on their roles during the project as well as a blueprint on how the emerged CERs are being distributed after their issuance. (Haites & Yamin, 2004; Yamin, 2005)

Once the project design has been completed, the second step called validation and registration begins. During this step the project is examined in order to ensure that all eligibility requirements are being met. The operational monitoring has been delegated to Designated Operational Entities (DOE) accredited by the Executive Board (EB) of the CDM. Projects validated by the DOE are automatically registered by the EB unless objections arise from at least three members of the board or from any involved parties. EB itself is responsible of approving new methodologies for determining baselines as well as formally registering projects and issuing CERs. Once the project has been registered, it is officially accepted as a CDM project. (Yamin, 2005; Haites & Yamin, 2004; United Nations, 2008)

CERs earned by the project are calculated by setting a baseline – business-as-usual scenario (BAU) – and comparing the scenario to the realized emission levels achieved by the project. The difference between these two determines the amount of issued CERs. Since the host-country has no commitments itself, this methodology creates strong incentives for the project participants to manipulate the baseline. Thus, solid supervision is needed to ensure that detailed requirements and procedures are being followed. Baselines should be transparent, project-specific and consider national circumstances. Construction of the baselines should be addressed so that the risk of carbon leakage is minimized. Carbon leakage means that the project achieves emission reductions within the scope of the project while emissions outside the project boundaries are increased. Small-scale CDM projects are exempted from the typical CDM project cycle and provided with simplified procedures as the relative cost for compliance is ought to arise to inappropriate levels. (Haites & Yamin, 2004; Yamin, 2005)

Monitoring is the third step in the project cycle and it imposes the project participants to collect information on both the actual and theoretical baseline emissions and to calculate emission reductions and sink enhancements based on the data. Monitoring is followed by verification and certification step wherein the information collected by the project participants is being reviewed by the DOE. The DOE then issues a written assurance that the CDM project has indeed achieved the reported emission reductions. (Haites & Yamin, 2004; Yamin, 2005)

Issuance of CERs is the final step within the project cycle during which the CDM registry administrator issues the number CERs determined in the project design document to the project participants. The issuance is enabled by a certification report by the DOE to the EB. There are three types of Kyoto units resulting from CDM projects: CERs are issued from emission reducing projects whilst temporary CERs (tCERs) and long-term CERs (lCERs) are issued from sink enhancement projects. (Yamin, 2005)

2.3.3 Joint Implementation

Joint Implementation (JI) is a project-based flexibility mechanism defined in Article 6 of the Kyoto Protocol. It has features from the CDM as a project-based mechanism but also from the IET since these projects are carried out in collaboration within parties with Kyoto commitments. The resulting emission reductions or sink enhancements earn parties Emission Reduction Units (ERUs), an allowance to emit one metric ton of CO_2-eqv into the atmosphere. The amount of ERUs earned is determined by comparing the realized emissions to the baseline emissions – a methodology discussed earlier in chapter 2.3.2. Double-counting of the emission reductions and sink enhancements is prevented by converting applicable amount of host party's AAUs into ERUs which are then being transferred into the buyer's account. Thus, JI project is always a zero-sum game wherein the overall number of Kyoto units remains the same. JI projects can be carried out by all countries with Kyoto commitments. However, host countries of these projects are commonly EIT parties wherein the MACs are lower. (Nykänen, et al., 2006)

JI projects do not create additional Kyoto units and hence the environmental integrity of the mechanism is lesser of a concern in comparison to CDM projects. Therefore, the need for bureaucratic multilateral oversight is – in theory – less needed. The protocol provides two alternatives for scrutiny called track 1 and track 2 procedures. Track 1 enables the host party to self-regulate the project, given that the party follows all track 1 eligibility requirements. Additional eligibility requirements which apply only to track 1 impose that the party must have a national evaluation system of its GHG emissions by sources and it must annually submit an inventory which fulfills the Kyoto requirements. Host party of the project is responsible of accepting and validating the projects as well as verifying the GHG emission reductions and sink enhancements. The host party can then independently transfer the agreed amount of ERUs to the buyer's account. (Haites & Yamin, 2004; Yamin, 2005)

Should the host party find itself in non-compliance with all track 1 eligibility requirements, it may use the track 2 procedure instead. Track 2 is subject to international oversight and the project cycle is similar to that of CDM. Project participants must jointly prepare a project design document which must be validated by independent entities (IEs). IEs play a similar role in operational monitoring as DOEs do in CDM projects. IEs are accredited by an article 6 supervisory committee, similar organization as the EB. A party is permitted at any time to change its methodology from track 1 procedure to track 2. This might be advantageous as ERUs acquired with track 2 are exempted from the CPR requirements discussed above in chapter 2.3.1 Furthermore, due to stronger international oversight track 2 procedure provides more credibility to the project. (Yamin, 2005)

3 The EU Emissions Trading System

The Kyoto protocol was adopted in 1997 and became effective eight years later in 2005 after the required condition of enough ratifications had been realized. The protocol imposed legally-binding GHG emission reduction targets for 39 parties including the European Community during the five-year-long commitment period from 2008 to 2012. Parties were allowed to freely choose the methods for achieving these targets and adoption of the protocol shifted the focus to the European level towards implementation. (United Nations, 1998; Valtonen, 2013) In the wake of adopting the Treaty of Lisbon in 2007 (2007/C/306/01), the European Community was renamed as the European Union. Henceforth, this thesis will consistently only use term European Union in order to avoid confusion.

Six months following the adoption, European Commission (EC) released a communication (European Commission, 1998) regarding EU's post-Kyoto strategy. This analysis was the first of its kind and at that time more detailed implementation strategy was still under the planning stage. Although the EU had been able to freeze its GHG emissions and was below the 1990 levels in accordance with the UNFCCC, the BAU scenario would not be enough to meet its Kyoto targets. Thus, EC proposed a comprehensive emission trading system across all economic sectors as the main tool to meet the commitments. This system would play under the rules of the protocol as emission trading is defined as one of the flexibility mechanisms. By creating an EU-wide system rather than several national ones, cost-effectiveness could be improved. The feasibility to authorize private entities to participate in emissions trading was also analyzed: inclusion would increase cost-efficiency even further, but on the other hand, would raise concerns regarding the state aid and distort of competition.

At the early stages of planning, there were two competing proposals on whether to base the trading system to the downstream on the emitting entities themselves or towards upstream to the fuel producers such as coalmines and gas and oil suppliers. A report by the commission (European Commission, 1999) approached this issue but was content to state that a combination of policy instruments will be needed for different types emitters and could not yet find any concrete proposals.

Due to the lack of prior experience from emissions trading, a step-by-step approach for the implementation was suggested. This would mean that at the beginning the number of GHGs and economic sectors included to emission trading was limited to those with high monitoring certainty and these limitations were to be gradually demolished over time. According to the EC, a step-by-step approach could be best implemented by creating an internal emission trading regime for the EU starting from 2005. This would provide much needed practical experience on multinational emission trading before the beginning of the Kyoto commitment period. (European Commission, 1998; European Commission, 1999)

The Green Paper (European Commission, 2000) was published a year later and it included some first propositions on the sectoral coverage. The private entities had been decided to include in the ETS. The EU had had successful experiences on imposing such environmental directives that only cover certain sectors and exclude the smallest emission sources from the legislation. This experience could be exploited in emissions trading too; however such differentiation puts on the pedestal the possible distort of competition between emitters included in and excluded from the emission trading.

With the most efficient policies in place, the estimated compliance cost to the EU's economy was 3.7 billion euros per year which corresponds to 0,06 % of the Gross Domestic Product

(GDP) of the Union (European Commission, 2004). On the contrary, the cheese slicer model wherein the national emission target is imposed equally to each sector without any possibility for emissions trading, neither national nor EU-wide, results in a compliance cost of 20.5 billion euros annually. The remaining options fall between these two figures, greater sectoral coverage lowering the cost of compliance. (Capros & Mantzos, 2000) At the time of these analyses the actual price of emission allowances was yet unclear which translates into higher level of uncertainty in the estimates. However, the figures do manage to present the magnitude of difference between different policy options.

European environmental policy had for long been favored by the "command-and-control" type of means of control while the USA had been the advocacy for market-based mechanisms such as emission trading. The decision by the USA not to ratify the Kyoto Protocol and the proactivity by the EU during the climate negotiations shifted this conventional power relation vice versa. The directive of establishing a scheme for GHG emission trading system within the EU was adopted in 2003 and the operation of EU ETS began in January 2005. Emission trading later became the cornerstone for emission reductions within the European Union (European Commission, 2018a; Yamin, 2005). This chapter presents the evolution of the European Union emission trading system, its operating principles, current state as well as future projections.

3.1 The EU Burden-Sharing Agreement

The EU wanted to strengthen its negotiation position prior the COP-3 meeting in Kyoto. This could be achieved only if common objectives were agreed upon as having separate targets for all 15 then-members of the EU would interfere the climate negotiations and turning it too polyphonic. On the other hand, identical reduction targets for each member state were not seen neither realistic nor fair because of the differences in economic development, power generation portfolios and energy consumption. Thus, the EU as a whole decided to negotiate a target for itself and later redistribute this target among its members through a burden-sharing agreement. This agreement only applies to those 15 member states that were members of the EU during the ratification of the Kyoto Protocol. (Yamin, 2005)

EU's initial emission reduction target for the climate negotiations in Kyoto was -15 % in 2010 compared to 1990 emission levels. Allocating this target across the countries was expressively difficult as the process consequently allocates the cost of climate actions. It should be noted that this cost is not a zero-sum game and the overall price can be reduced with cost-efficient allocation. (Valtonen, 2013) In addition to cost-effectiveness, also equity should be considered for the allocation. An investigation called Triptych approach (Phylipsen, et al., 1998) was carried out to study appropriate allocation of emission allowances. The study considered various national and regional circumstances such as population size and growth, economic development and structure, energy efficiency, fuel mix in energy production and the climate. Later evaluation (Marklund & Samakovlis, 2006) of the burden-sharing agreement confirmed that the agreement did indeed manage to properly consider these parameters.

The original reduction target by the EU changed from -15 % to -8 % during the negotiations in Kyoto. Even with reduction levels considerably eased from the planned, Triptych approach could be used for allocating the emission rights. The allocation had long-reaching impacts as the burden-sharing agreement laid the foundation of the EU ETS since similar sectoral analysis was used when countries decided how to allocate their allowances to the industry. (Yamin, 2005) Table 3 presents the emission reduction targets under the EU burden-sharing agreement during the commitment period from 2008 to 2012 as a percentage compared to the base year.

Table 3 Reduction targets for 15 countries of the European Union under the EU burden-sharing agreement during the commitment period from 2008 to 2012 as a percentage compared to the base year (Yamin, 2005).

Country	Target	Country	Target
Austria	-13 %	Italy	-6,5 %
Belguim	-7,5 %	Luxembourg	-28 %
Denmark	-21%	The Netherlands	-6 %
Finland	0 %	Portugal	+27 %
France	0%	Spain	+15 %
Germany	-21 %	Sweden	+4 %
Greece	+25 %	United Kingdom	-12,5 %
Ireland	+13 %	**The EU total**	**-8 %**

3.2 EU ETS begins (Phase I & II)

The EU ETS began its operation in January 1st 2005. It was the first international emission trading system and has remained the world's biggest one since then. The system is divided into phases and the first one took place during 2005-2007. The main purpose of the first phase was to serve as a trial period which provides practical experience and the possibility to test price formation as well as to set up a monitoring infrastructure before the second commitment period set by the protocol begins. Although the first phase occurred before the Kyoto commitment period, it was designed to be Kyoto-compatible from the beginning: the EU ETS is in accordance with international emissions trading set out in Article 17 of the protocol. Additionally, the credits (European Union Allowance, EUA) were normalized to CO_2-eqv as defined in the protocol. (European Commission, 2018a; Yamin, 2005)

The EU ETS follows the "cap-and-trade" principle meaning that the system has a certain pre-defined emission cap which cannot be exceeded. Emitters are allocated emission units at the end of each February and these units can then be traded freely. The allocation process is further discussed in chapter 3.2.1. Each emitter is allowed to pollute as much as they wish – given that they possess equivalent amount of allowances at the end of the period. The overall cap is the sum of all emission allowances in circulation which ensures the environmental integrity of the system. Banking – the possibility to transfer unused units for later use – was allowed within the first phase but not between phase I and phase II. From the second phase onwards, banking has been allowed within and across the phases. (Ellerman, et al., 2010; Perthuis & Trotignon, 2014)

One of the key advantages of a cap-and-trade system – as opposed to command-and-control approach or carbon taxation – is that it ensures that the desired emission reduction targets are actually realized and the country is effectively in compliance with its commitments. The cap can be defined far into the future, providing high level of predictivity on emission projections. Furthermore, this method could create revenues for governments if the emission allowances are auctioned. (European Commission, 2015)

The system was launched in all 25 countries that were members of the European Union in 2005. It covered some 11 000 installations and accounted for approximately 40 % of the EU's GHG emissions and 45 % of the CO_2 emissions. At the beginning, carbon dioxide was the only GHG included in the EU ETS. The remaining GHGs were excluded because the system was intended to be as simple as possible. Moreover, installing new devices to measure these emissions wanted to be avoided. The sectoral coverage was limited to carbon-intensive large installations and participation to the system was mandatory for all companies within these sectors. Additionally, countries could voluntarily opt-in both installations or full sectors and opt-out individual installations with certain conditions. (Nykänen, et al., 2006; Ellerman, et al., 2010) A list of sectors and their thresholds included in EU ETS at the beginning of the first phase is presented below in Table 4.

Table 4 Sectoral coverage and inclusion thresholds of the EU ETS at the beginning of phase I (2003/87/EC).

Energy activities
Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations)
Mineral oil refineries
Coke ovens
Production and processing of ferrous metals
Metal ore (including sulphide ore) roasting or sintering installations
Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2,5 tonnes per hour
Mineral industry
Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day
Installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day
Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day, and/or with a kiln capacity exceeding 4 m^3 and with a setting density per kiln exceeding 300 kg/m^3
Other activities
Industrial plants for the production of (a) pulp from timber or other fibrous materials (b) paper and board with a production capacity exceeding 20 tonnes per day

During the first two phases the system has experienced several expansions; geographical, sectoral and in terms of gas coverage. The then-25 members of the European Union were joined by Romania and Bulgaria with the enlargement of the EU in 2007. Norway, Liechtenstein and Iceland joined the EU ETS at the beginning of phase II in 2008. From 2008 onwards, countries may also voluntarily include N_2O emissions in emission trading. Aviation was included in EU ETS in 2012; however, this expansion was and still is limited to only those flights with both the place of origin and the destination within countries included in EU ETS. Figure 4 presents the key changes in the structure of the system within the first two phases. (European Commission, 2015)

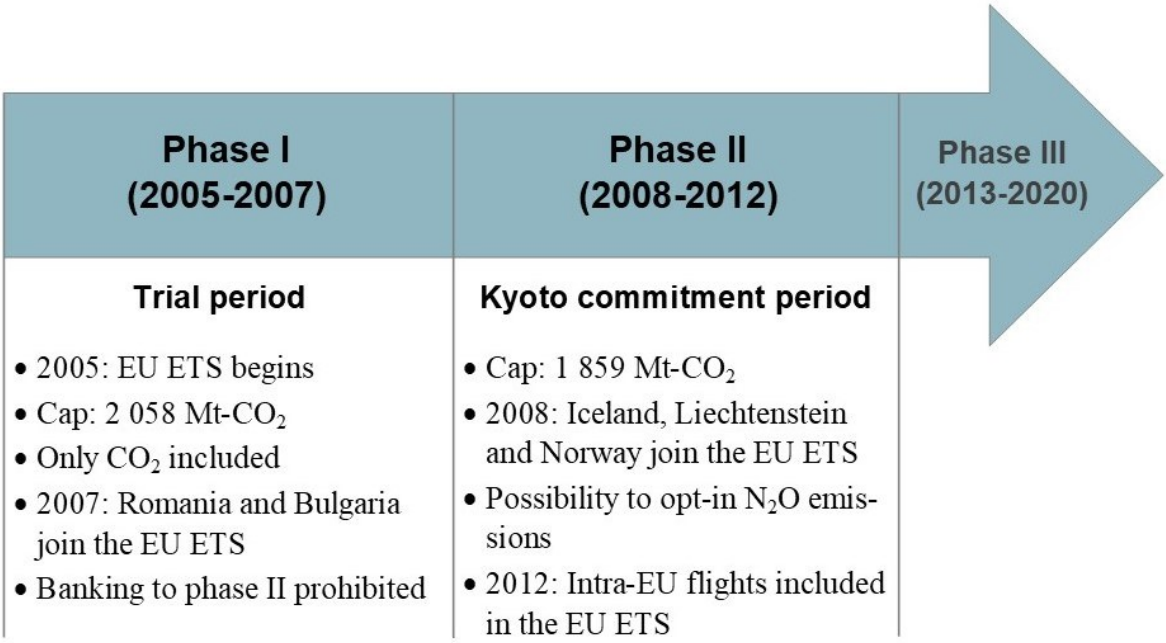

Figure 4 Summary of the main characteristics and modifications of the EU ETS during the first two phases

Emission trading is a cornerstone in EU's climate policy to tackle the climate change. It should be noted; however, that the system is not the only instrument being used and some policies are overlapping with the EU ETS. E.g. targets for promoting renewable energy are already covered by the EU ETS. Although the LULUCF sector does not count towards EU-wide reduction targets, the sector has an important role in reducing the net emissions. However, further analysis of the LULUCF sector is outside the scope of this thesis.

Another point of interest are the emissions from sectors not covered by the EU ETS. This sector is regulated by the Effort Sharing Decision (ESD) which imposes individual country-specific reduction targets for the non-ETS sector. The ESD sector is discussed further in chapter 4 but a short list of sectors not covered or are only partially covered by the EU ETS is provided below. (European Environment Agency, 2016)

- Transportation (intra-EU flights are covered by the EU ETS)
- Energy consumption in buildings (electricity and some of the heating are covered)
- Agriculture
- Industry (sectors mentioned in Table 4 are covered)
- Waste management.

3.2.1 Allocation process

Allocation of emission allowances from national authorities to the emitting private entities was a decentralized process and it was carried out through National Allocation Plans (NAPs). These documents are prepared by national authorities in each member state and they determine the overall number of EUAs each company and sector receive during a given phase. It also ensures that the country will be in compliance with its Kyoto targets as the overall number of EAUs distributed cannot exceed the Kyoto commitments of the country. Additionally, the plan must contain information on how the country will distribute its emission reduction efforts between the ETS and non-ETS sectors as well as the amount of possible acquisitions by Kyoto mechanisms. Members of the EU had to publish their NAPs well before the beginning of the phases. (Yamin, 2005)

Preparations for the first NAP for phase I was characterized by lax reduction targets, poor emission data and unrealistic deadlines. The reduction targets remained unambitious since the main purpose of the first phase was not the emission reductions themselves. In fact, there were only two rules to follow: the overall cap of each country had to be below the BAU scenario as well as below a linear line drawn between the year 1990 and the target determined by the burden sharing agreement. EC was given the authority to reject those NAPs that did not meet this criterion and it also did so in several occasions. (Ellerman, et al., 2010)

Poor data caused significant uncertainties for the allocation as there was no prior information on installation-specific emissions. GHG inventories established earlier for UNFCCC purposes contained only sector-specific information and were calculated based on the fuel consumption. Poor data was amplified by unrealistic deadlines set by the commission. After all, only four countries managed prepare their NAPs in time and another four could not complete until the EU ETS was already running. It can be argued; however, that the tight schedule was indeed necessary in order to set up the system within the desired schedule. All the foregoing issues resulted a clear over-allocation of EUAs which was not detected until the emission data was first released in 2006. (Ellerman, et al., 2010)

Cap-setting for the second period was rather similar process compared to its predecessor. Many root causes for the difficulties experienced during the preparation of the first NAP had been overcame: issues regarding the poor data disappeared by the release of the verified emissions data from 2005, the deadlines were this time more realistic and more ambitious emission targets were imposed in order to meet the Kyoto targets. New challenges emerged as the limit for credit acquisitions by JI and CDM projects needed to be set and countries needed to find the balance for the reductions between these acquisitions as well as ETS and non-ETS sectors. Country-specific limits for acquisitions were set ranging from zero to 20,6 percent. (Ellerman, et al., 2010)

During the first two phases the emission allowances were allocated to the participants mostly for free. The emission trading directive (2003/87/EC) determines that at least 95 % of the EUAs must be given to the companies free of charge while maximum 5 % can be auctioned. During the first phase only four countries decided to use auctioning as part of their allocation process. For the second phase countries could auction up to 10 % of the EAUs and 9 of them decided to do so. However, free allocation did remain as the principle method of allocation throughout the first two phases. (Schleich, et al., 2009)

The rationale behind why so many governments decided to disregard the extra revenues from auctioning lies in the need of gaining acceptability towards the system. This was particularly crucial in order to gain the support from the industry. (Ellerman, et al., 2010) Figure 5 presents the quantity of emission allowances allocated for free as well as the amount of allowances auctioned during the first two phases of EU ETS. NAPs were used to allocate the emission allowances for phase I and for phase II. This method was replaced by benchmarking from the beginning of phase III. (European Commission, 2015) Allocation process for phase III and phase IV is discussed later in chapter 3.3.1.

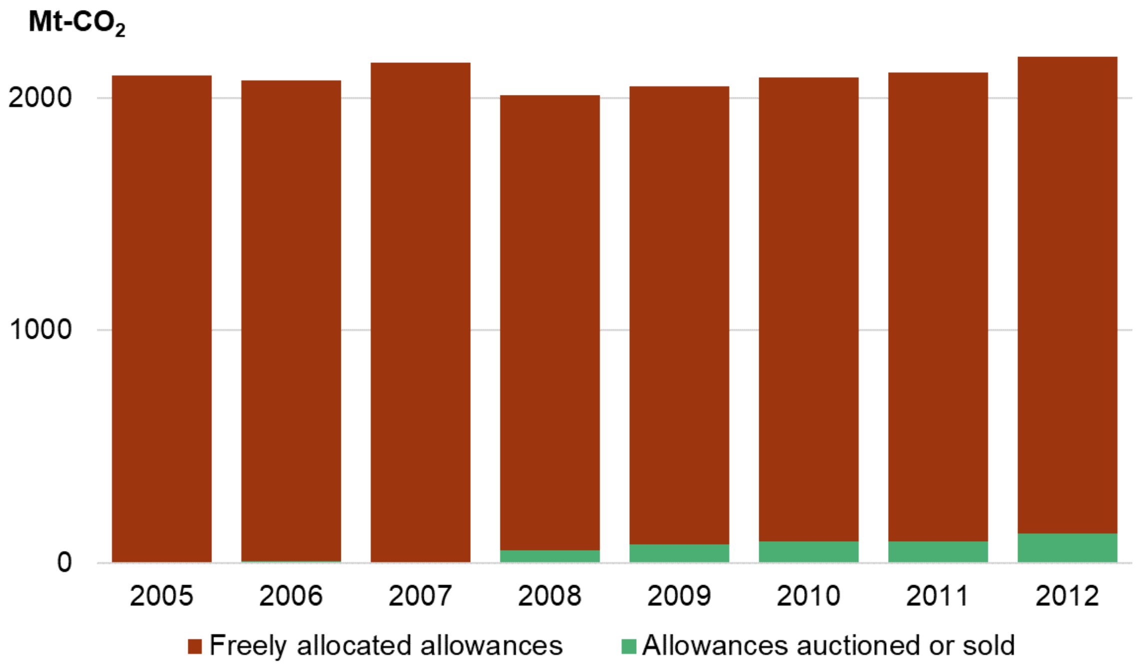

Figure 5 Freely allocated emission allowances and emission allowances auctioned or sold during the first two phases (European Environment Agency, 2019c).

3.2.2 Price formation

Emission trading is a market-based mechanism which means that the price of an allowance is determined by the supply and demand. Any commodity market is always susceptible to current policies but unlike most markets, the supply of emission allowances is completely generated by political decisions. On a system without any limits for banking, the expected scarcity of allowances determines the price. As politics can be erratic, sometimes even simple discussions on future climate and energy policies or other public policies with an interaction with emission trading can have a significant effect on the price. In addition to the politics, financial situation, current energy prices and possibility to use offsets via Kyoto mechanisms altogether contribute to the price formation of the emission allowance. (Ellerman, et al., 2010; Perthuis & Trotignon, 2014)

When the EU ETS was first introduced, there was not much exact data available on the emissions from the installations covered by the system and consequently the price was largely based on speculations. The high level of uncertainty caused strong price fluctuations at the beginning of phase I. Despite the high volatility, price was effectively increasing from the beginning which indicates that the market believed in the scarcity of allowances. Later both the uncertainty and belief in scarcity were swept away in 2006 with the first release of previous year's verified installation-specific emission data. The anticipated 4 percent deficit was confirmed to be a surplus of 4 percent which soon caused a sharp plummet in the price. This significant abundance of EUAs eventually caused the price drop down to zero in 2007 as banking was forbidden between the first two phases meaning that the remaining allowances from the first phase could not be used later. (Ellerman, et al., 2010) Figure 6 presents the price of the EUA during 2005-2012.

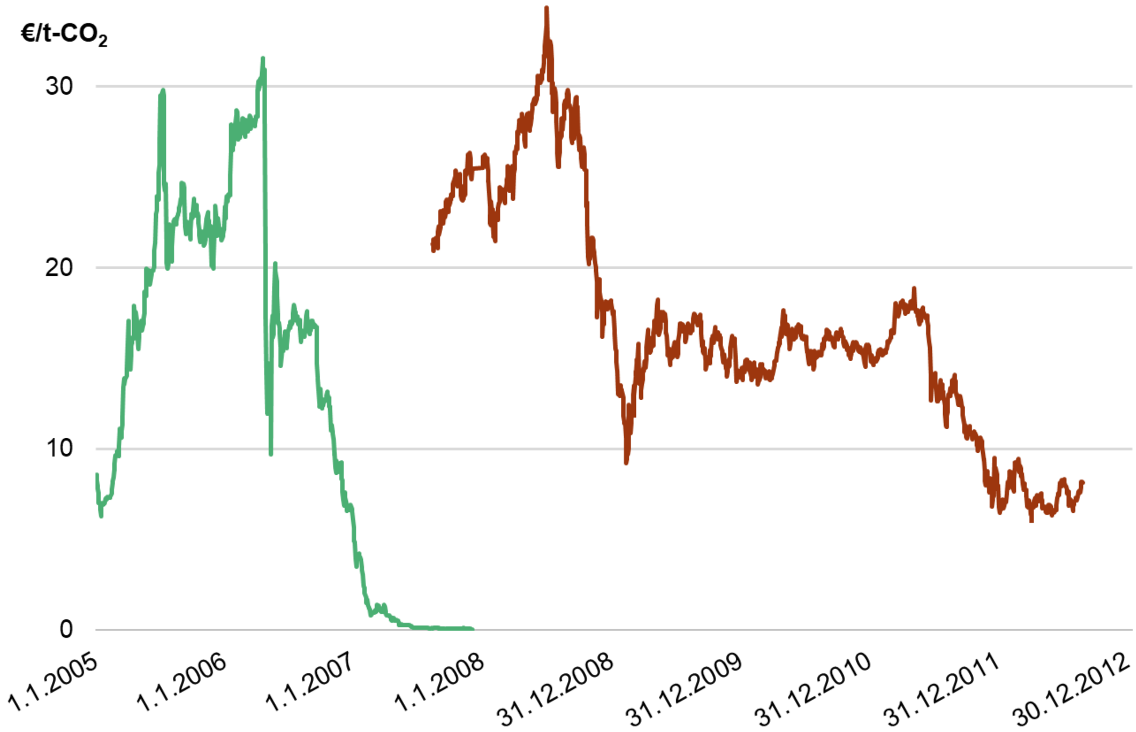

Figure 6 EUA future prices (EUA 2007 and EUA 2012) during the first two phases (European Environment Agency, 2018a).

Many of the challenges experienced during the first years of operation were overcame by the beginning of the second phase by taking advantage of the experience gained earlier. Tighter emission targets, inability to use banked allowances and strong economic growth all together increased the price pressure at the beginning of phase II. The price increase was even further accelerated by the ongoing political discussions and the regulations which were adopted concerning EU's targets for 2020 with respect to GHG emissions, renewable energy and energy efficiency. (Perthuis & Trotignon, 2014)

It was soon discovered; however, that the challenges solved earlier were only replaced by new ones. Financial crisis struck the world in 2008 and caused production levels to decline. This decreased the energy consumption and thus, reduced the demand of emission allowances. As a result the price collapsed from almost 35 €/t-CO_2 to 9 €/t-CO_2 in just six months. The price soon found its new equilibrium at around 15 €/t-CO_2 and remained more or less the same for two years during the slow recovery of the economy. The price increased for a short while as the nuclear power plant accident in Fukushima in 2011 increased the anticipated demand for emission allowances. This increase; however, was only a momentary one and the price started slipping soon after. At the end of phase II in December 2012 the price was barely above 5 €/t-CO_2. (Perthuis & Trotignon, 2014; Koch, et al., 2014)

The unexpected financial crisis coupled with weak long-term expectations for economic growth alone cannot fully explain the price decline. Structural weaknesses such as subsidies and other support mechanisms for renewable energy as well as energy efficiency targets both reduce the demand for that electricity production which is covered by the EU ETS. This will drive emission reductions irrespective of the price of carbon. Other policy measures besides emission trading can be justified but disregarding these measures in the design of the EU ETS was the mainstay of the price decline during 2011-2012. (Perthuis & Trotignon, 2014)

Yet another reasoning eroding the market during the first two phases was the large availability of extra allowances acquired by CDM and JI projects together with erratic regulation regarding their usage. Nearly constant use of 80 million offsets per year skyrocketed in 2010 with the announcement by the commission on upcoming restrictions for their usage. Private entities rushed to use their offsets before they would become worthless which caused a price collapse. The price of the offsets had already been differentiated from the price of the EUA but the possibility to comply with emission targets with cheap offsets radiated to the price of EUAs too. (Perthuis & Trotignon, 2014; Koch, et al., 2014)

3.3 EU ETS post 2013 (phase III and IV)

Phase III of the EU ETS commenced in 2013 and for a variety of reasons discussed above the system's ability to address emission reductions in a cost-effective manner was controversial. Several structural changes were implemented to address these challenges by adopting revisions into the system in 2008. The overall cap of GHG emissions was set at 2 080 Mt of CO_2-eqv for 2013 with an annual reduction factor of 1,74 %. This reduction percentage applies throughout the third phase during 2013-2020 and will increase to 2,2 % when the fourth phase begins in 2021. The reductions within emission trading sector will add up to a decrease of 21 % in 2020 and 43 % in 2030 compared to 2005. In 2018 the EU ETS covers approximately half of the carbon dioxide and almost 45 % of all GHG emissions in the Europe. (Borghesi & Flori, 2018; European Commission, 2015)

Furthermore, auctioning was now the main allocation technique although industry sectors other than electricity producers continue receiving a portion of the allowances for free. National allocation plans were replaced by benchmarking when determining the allocation of free allowances. In line with the initial objective of gradual expansion of the scheme, both geographically and sector-wise, new industry sectors such as production aluminium, petrochemicals and other chemicals as well as new GHGs such as N_2O and PFCs were included in the EU ETS. The system expanded geographically by including Croatia with the enlargement of the EU. These expansions accounted for approximately 200 Mt of CO_2-eqv. In 2013 the EU ETS covered some 13 500 stationary installations in 31 countries. (Ellerman, et al., 2016; European Commission, 2015)

Perhaps the biggest challenge associated with the EU ETS was the substantially accumulated surplus of emission allowances. This was addressed first by backloading 900 million allowances from the auctions during 2014-2016 and secondly by introducing new stability-enhancing instrument, Market Stability Reserve (MSR), into the system. MSR is further discussed in chapter 3.3.3. The backloaded allowances were later decided to be placed directly into the reserve. (Chaton, et al., 2018) Figure 7 presents the main characteristics and modifications of the EU ETS during the phase III and those modifications for phase IV which have already been adopted.

Figure 7 Summary of the main characteristics and modifications of the EU ETS during the phase III and those modifications for phase IV that have already been officially adopted

3.3.1 Allocation process

While countries could auction up to 5 % of the total amount of allocated emission allowances during the phase I and up to 10 % during the phase II, the reality was that only insignificant proportion decided to do so. One of the key changes accompanied with the transition from the second phase to the phase III was the gradual shift from free allocation towards auctioning. The allocation method was also changed from much criticized NAPs to a simpler and more transparent documents called National Implementation Measures (NIMs). NIMs are prepared by each member state and they are being constructed according to fully harmonized rules. As earlier with NAPs, NIMs must be approved by the commission prior acceptance. (Ellerman, et al., 2010; European Commission, 2015)

At the beginning of phase III almost half of the EUAs were auctioned while another half was allocated for free. Year by year this balance is being tilted progressively towards auctioning. Electricity producers and other industries have differentiated auctioning shares: power producers will have to buy all the needed allowances from 2013 onwards while industry sectors begin the phase with 80 % of the allowances allocated for free. The share of free allocation for other industries than power producers is linearly reduced and reaches 30 % in 2020. The share of allowances other industries will receive for free throughout the fourth phase is still undecided as of December 2018 but it is likely that some level of free allocation will continue until 2030. (European Commission, 2015; 2018/410/EU)

The amount of allowances given for installations was based on historical emissions during the first two phases. This so-called grandfathering method was highly criticized for rewarding carbon-intensive and inefficient installations while disincentivizing investments towards cleaner technologies. Starting from 2013 free allocation for industries has been based on benchmarking which is a reference value representing the 10 % most carbon-efficient installations in the EU. The benchmark value is determined by constructing a benchmark curve and finding the installation with 10 % most efficient production level. This is done separately for each sector and industrial process and the value is given in kilograms of CO_2-eqv per product produced. Each installation will receive free allowances according to the benchmark, multiplied by the historical production. With benchmarking a considerable majority of installations will be short on allowances even with 100 % free allocation. On the other hand, the most efficient ones will receive a surplus of allowances. (European Commission, 2015). The benchmark value will change from 10 % to 15 % at the beginning of phase IV in 2020 (2018/410/EU). Figure 8 presents the process of defining the benchmark value according to the benchmark curve.

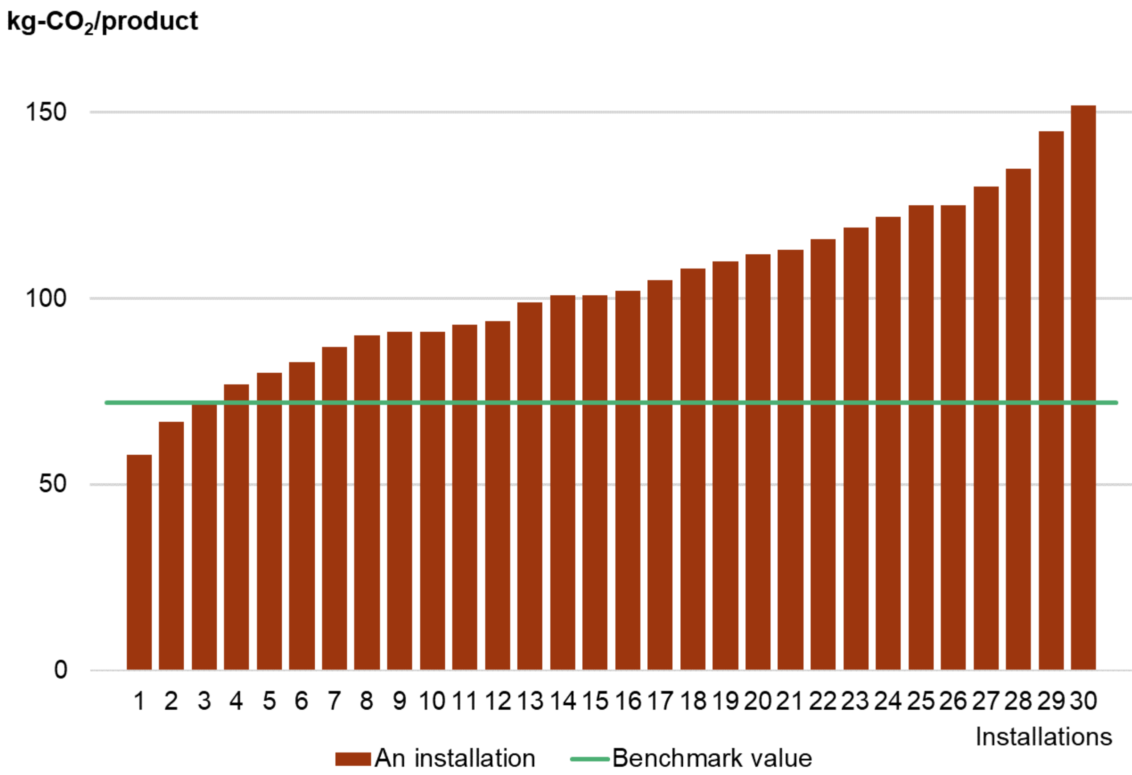

Figure 8 Benchmark curve for a hypothetical product

An important consideration regarding the allocation process is the treatment of industrial sectors prone to carbon leakage. Carbon leakage refers to a situation in which unsymmetrical climate policies between regions induce companies to relocate their operations to carbon havens – areas with little or no emission constraints. This will increase the reduction cost and might even result in as an overall increase of global GHG emissions and thus, undercut the environmental integrity. Carbon leakage was not so much of a problem during first two phases as most allowances were allocated for free but the gradual shift towards auctioning demanded proper re-assessing of the issue. (Paroussos, et al., 2015; Böhringer, et al., 2017)

The risk of carbon leakage is pronounced within global and carbon-intensive sectors such as cement, chemical and metal industries. In order not to put its companies to economic disadvantages because of the price of carbon, the EU issues 100 % free emission allowances for industrial installations on sectors exposed to a significant risk of carbon leakage, up to the benchmark value determined earlier. (Paroussos, et al., 2015; Böhringer, et al., 2017) As of December 2018, free allocation for sectors exposed to a significant risk of carbon leakage is expected to continue until 2030 (2018/410/EU). Table 5 presents the shares of free allocation for electricity producers, industry sectors other than electricity producers and for industry sectors deemed exposed to carbon leakage during 2013-2030.

*Table 5 Shares of free allocation for electricity producers, industry sectors other than electricity producers and for industry sectors deemed exposed to carbon leakage (European Commission, 2015) * = unadopted estimate (2018/410/EU).*

Share of free allocation based on benchmarks	2013	2014	2015	2016	2017	2018	2019	2020	2021
Electricity production	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Other industry sectors	80 %	72,9 %	65,7 %	58,6 %	51,4 %	44,2 %	37,1 %	30 %	30 %
Industry sectors deemed exposed to carbon leakage	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Share of free allocation based on benchmarks	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Electricity production	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Other industry sectors	30 %	30 %	30 %	30 %	30 % *	22,5 % *	15 % *	7,5 % *	0 % *
Industry sectors deemed exposed to carbon leakage	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %

3.3.2 Auctioning

Starting from 2013 auctioning has been the principle method for allocation of emission allowances. Auctioning can be considered as more transparent process compared to free allocation. Furthermore, it actualizes the philosophy that the polluter should provide financial reimbursement. Auctioning has two possible online platforms: the European Energy Exchange (EEX) in Germany and Intercontinental Exchange Futures Europe (ICE) in the United Kingdom. EEX operates as a common auction platform for most participants of the EU ETS. Germany and Poland carry out their own auctions through EEX while United Kingdom does the same through ICE. The auctions take place several times per week and the dates as well as the amount of EUAs on sale for each auction are published well in advance. (European Commission, 2015; European Commission, 2018b)

Bidders place their offers without being aware of each other's bids. Each bid must state the amount of EUAs the bidder wishes to purchase and at what price, minimum pile of allowances being 500 or 1000 depending on the platform. The bids are then being arranged according to the price from the highest to the lowest and the offers are accepted until the pre-defined auction volume is satisfied. The last bid that was accepted determines the clearing price of the auction and each successful bid will pay the same clearing price. Auction will be cancelled if the bidding volume does not exceed the auction volume or the clearing price is below the auction reserve price defined by the auction platform. A large proportion of the revenues generated by the auctions has been used for promoting climate-friendly technologies. (European Commission, 2015; European Commission, 2018b)

3.3.3 Market Stability Reserve

An important instrument for restoring the EU ETS back on its track as a method providing cost-effective emission reductions was the introduction of the MSR into the system by revising the emission trading directive in 2015. The main purpose of the MSR was to terminate the long-lasting situation in which the EU ETS operates with significant oversupply of emission allowances. This oversupply had been accumulating over the years due to economic recession, excessive usage of offsets and overlapping policies such as subsidies for renewable energy. (Chaton, et al., 2018)

MSR became operational in January 2019 its function is to react changes in demand by altering the supply of allowances according to transparent and pre-defined rules. In practical terms this is done by deducting a certain amount of EUAs from the auction volume and placing that into the reserve. On the contrary, MSR will inject additional allowances into the market – that is, through an increase in auctioning – if the availability of allowances drops too low. The first reserve feed period will take place between January and August 2019 and lies its foundation on the calculations released in May 2018 on the overall amount of allowances in circulation. The exact terms determining the prerequisites and amounts for both the injection and the withhold by the MSR has been set as follows: (Chaton, et al., 2018; Hepburn, et al., 2016)

1) If the surplus of allowances in circulation is above 833 million, MSR withholds 12 % of this surplus by subtracting the amount from next year's auction volumes.
2) If the surplus of allowances in circulation is below 400 million, MSR injects additional 100 million allowances into the market through next year's auctions, given that such amount exists in the reserve
3) If the price of an allowance stays at least three times higher than the average price during the preceding two years for six consecutive months, MSR injects additional 100 million allowances into the market through next year's auctions, given that such amount exists in the reserve

Thus, the long-term plan of the reserve is to maintain the surplus between 400 million and 833 million EUAs. The MSR has a boosted effect of 24 % during the first five years of operation and the regular feeding rate of 12 % will be returned from 2024 onwards. The earlier plan of postponing the allocation of 900 million allowances during 2014-2016 – 400 million in 2014, 300 million in 2015 and 200 million in 2016 – was overruled and the corresponding amount was placed directly into the MSR. Due to the decision to withhold 900 million allowances, the accumulated surplus has begun to decrease from its peak value of 2,1 billion EUAs in 2013. Since the decision to adopt MSR into the EU ETS the price of carbon nearly tripled in just six months and has stayed at around 20 €/t-CO_2 since the latter part of 2018. (European Environment Agency, 2018b; Sandbag, 2019)

MSR is expected to have a significant impact on the surplus of allowances during following years. In addition for solving the short-term oversupply in the market, the reserve is expected to provide resilience from potential upcoming economic shocks or other causes for future imbalances such as unexpected technology advances. Figure 9 presents the available allowances, cumulative surplus, allowances in MSR, emissions cap, MSR thresholds as well as emissions from the ETS sector from 2008 until 2017 as well as projections of these parameters until 2030. (European Environment Agency, 2018b)

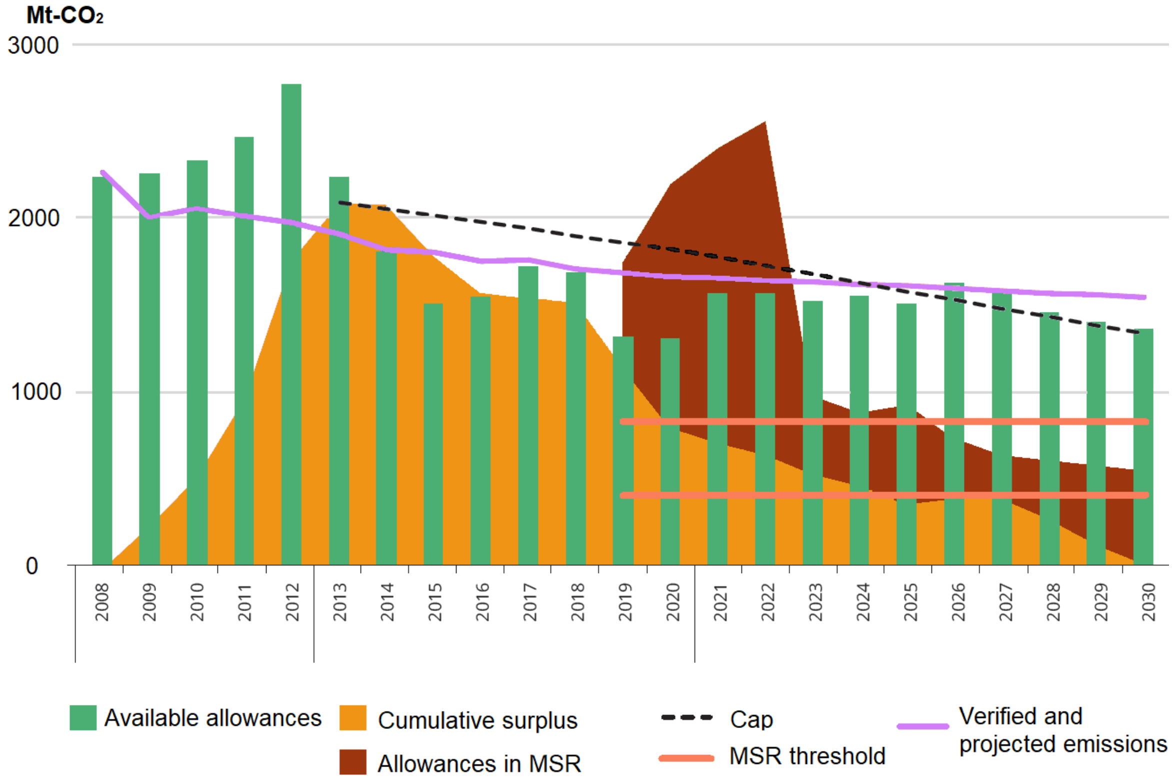

Figure 9 Available allowances, cumulative surplus, allowances in MSR, emissions cap, MSR thresholds as well as emissions from the ETS sectors (European Environment Agency, 2018b). Modified by the author.

3.3.4 Price formation

Since banking has been allowed from the beginning of the second phase, no such price differentiation as the one experienced in transition from phase I to phase II has occurred thereafter. Due to the large surplus of emission allowances the price of the EUA was barely above 5 €/t-CO_2 at the beginning of the phase III. (Perthuis & Trotignon, 2014) The reasons that had led to this situation and undesired price levels during first two phases are being discussed above in chapter 3.2 and its subsections.

Despite implementing reinforcement policies such as backloading, annually reducing cap or gradually decreased share of free allocation, the price of EUA stayed between 5-10 €/t-CO_2 until the beginning of the 2018. Most analysts considered this price level to be far too low to direct emission reductions cost-effectively. Although the decision to backload 900 million allowances did manage to curb the short-term surplus, it did not change the implications of market participants that the abundance of allowances will continue. It was only after the decisions to implement MSR in the EU ETS as well as place the backloaded EUAs directly into the MSR when the price began its surge towards the current levels above 20 €/t-CO_2. (Borghesi & Flori, 2018; Fan, et al., 2017) Figure 10 presents the price of the EUA from 2013 onwards.

Figure 10 Development of the EUA price since January 2013 (Sandbag, 2019).

The recent price development of EUA to around 20 euros is beginning to reach levels in which one of the key short-term abatement measures, fuel switching from coal to less-emitting natural gas, begins to be triggered. (Soliman & Nasir, 2018) According to the study carried out by (Mosby & Knell, 2018); however, the price of carbon should be 35-70 euros per a ton of CO_2 by 2020 and 44-88 € by 2030 in order to meet the emission reduction targets set by the Paris Agreement.

The forecasts for upcoming EUA prices vary considerably ranging from 25-65 €/t-CO_2 in 2020 to 20-110 €/t-CO_2 in 2030, indicating strong uncertainties related to the price formation (Edenhofer, et al., 2017; Twidale, 2018; Carbon Tracker Initiative, 2018; Refinitiv, 2018). Despite the noticeable variation, polyphonic estimates can be aggregated so that no predictions suggest that the price would fall permanently below the 20 euros threshold anymore.

3.4 Monitoring, Reporting and Verification

Monitoring, reporting and verification process is an indispensable component of the EU ETS and all the participants of the emission trading system must comply with the monitoring and reporting regulation (EU No 601/2012) as well as with the verification regulation (EU No 600/2012). The obligation of the operators to annually report their GHG emissions as well as to surrender an equivalent amount of emission allowances is a key characteristic ensuring the environmental integrity of the EU ETS. The reported emissions must be verified and any operator or installation who does not comply with the regulations will face severe penalties.

The whole MRV process has been harmonized on the European level since the beginning of phase III in 2013. (European Commission, 2015)

The obligation to comply with the MRV requirements in EU ETS is addressed to the emission sources themselves. This approach is called downstream regulation, in contrast with the upstream regulation wherein compliance is required by the entities that produce the emitting materials, such as fuels. The upstream approach was rejected for a couple of reasons. Firstly, the projected price of emission allowances was expected to stay far below the current fuel tax rates of most countries, increasing the price only marginally. The impacts on consumption would remain moderate, and thus undermining the regulatory impact. The second concern came from finance ministers. They feared that emission allowances – inexpensive compared to tax rates of transport fuels – could fully replace the fuel taxation in the future in order to avoid double taxation. This would have adverse effects on the state budget. (Ellerman, et al., 2010)

Each installation operating under the EU ETS must hold a GHG emission permit issued by a competent authority. The permit is granted through an application and it must contain information on the location of the installation, the technology used as well as on the use of fuels and other materials which will lead to GHG emissions. (2003/87/EC) In addition to these requirements, the operator must develop a monitoring plan which describes the duties of the operator regarding the EU ETS. The monitoring plan must describe in detail the method of data collection, sampling of fuels and materials as well as its analysis, maintenance of measuring devices and illustration on calculations. The competent authority has at any times the right to carry out inspections to assure that the monitoring plan is been implemented. Monitoring plan should be improved continuously whenever improvement points are found and significant changes must be approved by the competent authority. Once approved, the monitoring plan is thereafter being followed during the annual compliance cycle. (European Commission, 2017)

As opposed to the monitoring plan which is developed only once, albeit regularly updated, the compliance cycle is an ongoing process repeated each calendar year. A key document related to the compliance with MRV is the Annual Emissions Report (AER) describing the GHG emissions from the previous year. All installations, operators and aircraft operators included in the EU ETS must hand over the AER to the competent authority every year by 31st March. This report must include all emission streams of the installation in terms of CO_2-eqv. Prior submitting, the report must be verified by an independent accredited verifier who must be granted a permission for all the necessary premises of the installation. The competent authority then checks the report and requires corrections, if applicable. The equivalent amount of emission allowances to the actual emissions must be surrendered by the operator by 30th April. Penalty for non-compliance is 100 €/t-CO_2-eqv and paying the sanction does not exempt from surrendering the allowances. (European Commission, 2017)

In order to avoid unreasonable monitoring costs, the required data quality depends on the annual emissions of the installation. These levels of data quality are called tiers and they represent the required precision and accuracy for fuel quantity, calorific value, emission factor, biomass fraction and oxidation factor. An operator may request a derogation for its tier if cost-effectiveness of the MRV is threatened or if the measurement of a certain parameter is technically not feasible. Table 6 presents the data quality requirements regarding monitoring and reporting of GHG emissions. (European Commission, 2017; European Commission, 2015)

Table 6 Data quality requirements regarding monitoring and reporting of GHG emissions (European Commission, 2015).

<table>
<tr><th>Tier level</th><th>Maximum uncertainity in fuel amount</th><th>Net calorific value</th><th>Emission factor</th><th>Biomass Fraction</th><th>Oxidation factor</th></tr>
<tr><td>Tier 4</td><td>± 1,5 %</td><td rowspan="2">Must be determined by analysis</td><td rowspan="2">Must be determined by analysis</td><td rowspan="3">Must be determined by analysis</td><td rowspan="2">Must be determined by analysis</td></tr>
<tr><td>Tier 3</td><td>± 2,5 %</td></tr>
<tr><td>Tier 2</td><td>± 5 %</td><td>Country specific factors or values from fuel invoices</td><td>Country specific factors or proxy values from analysis</td><td>Country specific factors</td></tr>
<tr><td>Tier 1</td><td>± 7,5 %</td><td>Standard factors from MRV regulation</td><td>Standard factors from MRV regulation</td><td>Standard factors</td><td>1</td></tr>
</table>

Aircraft operators have their own set of rules regarding the MRV that are slightly differentiated from those of the installations. Monitoring plan needs to be prepared prior the permission to operate is being granted. Aircraft operators calculate their CO_2 emissions by multiplying the consumed fuel with the emission factor. This calculation is done individually for each flight. Tier system for aviation is extensively simplified with just two given levels for data quality. Most operators are required to report their fuel consumption with an uncertainty level of ±2,5 % while small emitters emitting annually less than 50 kilotons, may report with a 5 % uncertainty. Since there are only few types of commonly used fuels in aviation having highly strict quality limits, standard factors provided by the fuel suppliers can be used to determine the emission factor. A laboratory analysis is required only if uncommon fuels are being used. Throughout the monitoring period, aircraft operators must follow the same deadlines for issuing the verification report and surrendering the allowances as other installations. (European Commission, 2018c)

4 European Heating Sector

One of the fundamental ideas when introducing the EU ETS at the turn of the millennium was the gradual expansion of the scope of the system over time (Ellerman, et al., 2010). Minor expansions have been implemented indeed, but the scale of these measures has arguably been mere modest. Currently the share of emissions covered by the EU ETS is lower than in 2005 when the system commenced. (European Environment Agency, 2019a; European Environment Agency, 2019b) During the recent years the main focus has rightly been targeted towards the structural weaknesses of the system, in particular lower-than-expected price of emission allowances. However, at the beginning of 2019 the state of EU ETS now appears stronger with significantly increased price of EUA while the introduction of MSR into the system implies that such steady development is expected to continue. The current strong position would pave the way for further expansion of the system, in accordance with the initial vision.

Most of the GHG emissions falling outside the scope of the EU ETS are currently been governed by the effort sharing decision (2018/842/EU). In 2016 the overall GHG emissions in the EU were 4 400 Mt CO_2-eqv and of this 2 540 CO_2-eqv or 57 % falls under the ESD sector. These emissions consist of transportation other than domestic aviation, buildings, agriculture, waste as well as that energy and manufacturing industry which is not included in the emission trading. Emissions from the ESD sector have decreased much slower compared to the ETS sector, reflecting the diversity of the emission sources as well as the lack of mitigation potential within the ESD sector. Emissions from LULUCF sector and emissions from international shipping are not been governed neither by the ETS nor the ESD regulation. (European Environment Agency, 2019a; European Environment Agency, 2019b). Figure 11 presents the GHG emissions by sector governed by the ESD in 2015.

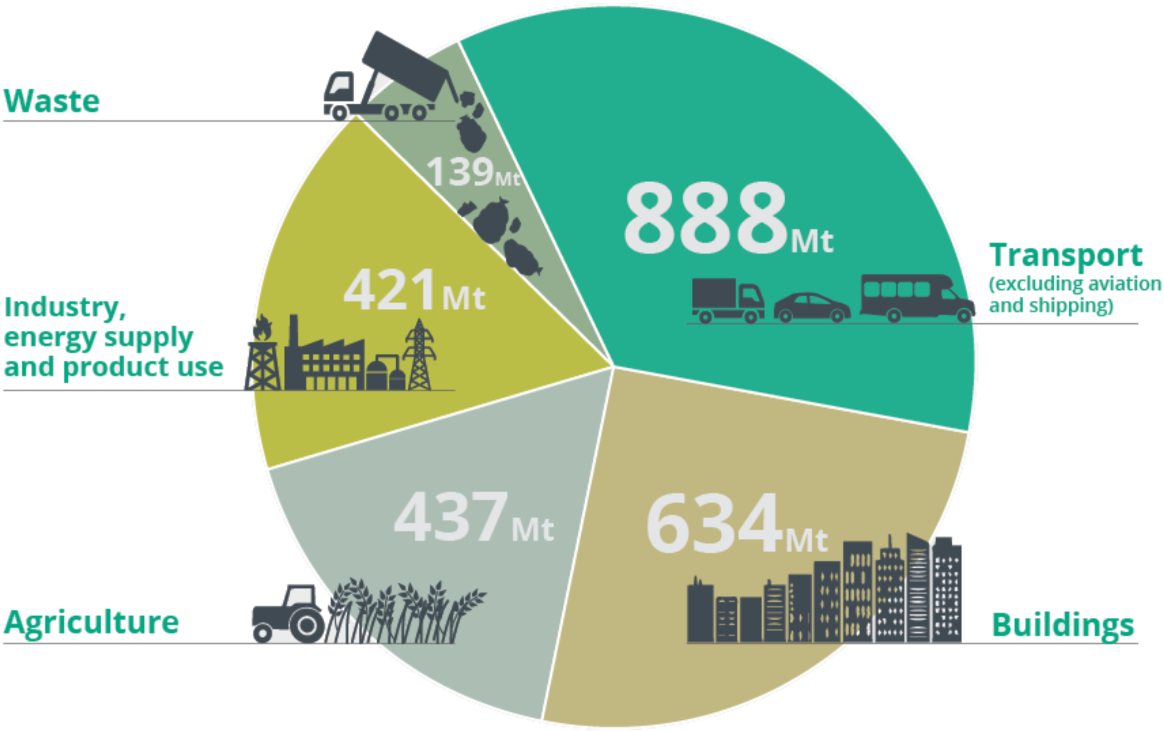

Figure 11 GHG emissions outside of the EU ETS by sector in 2016 (European Council, 2018).

Both the EU ETS and ESD belong to EU's larger framework on climate and energy with projections to reduce GHG emissions by at least 80 % by 2050 compared to 1990 levels. This objective has two milestones in 2020 and 2030 with overall reduction targets of -20 % and -40 %, respectively. The reduction targets have been split between the ETS and ESD sectors. ETS sector is governed on a European level with annually decreasing cap as explained in previous chapter while each member state has their own national target for the ESD sector. Countries are ranked according to the GDP and those with better economic capacity face more ambitious reduction targets. The reduction targets appointed to the ETS sector are more ambitious as emission trading is expected to provide considerably bigger potential for cost-effective reductions. (Babonneau, et al., 2018) Table 7 presents the overall reduction target as well as specific targets for ESD and ETS sectors.

Table 7 Overall GHG emission reduction target as well as specific targets for ESD and ETS sectors (Babonneau, et al., 2018).

Year	2020	2030	2050
Overall target (base year: 1990)	-20 %	-40 %	At least 80 %
ETS sector (base year: 2005)	-21 %	-43 %	Undecieed
ESD sector (base year: 2005)	-10 %	-30 %	Undecided
National ESD targets, range	-20 % – 20 %	-40 % – 0 %	-

In addition to certain European-wide regulations and standards imposed by the EU, countries implement various strategies through national policies in order to meet these targets. In contrast with the emissions covered by the EU ETS, there is no certainty that the ESD objectives are actually realized. The latest emission data from 2017 reveals that despite the overall EU objective is ought to be achieved, 6 countries out of 28 are not on track to meet their ESD targets for 2020. With stricter ESD target imposed for 2030 the overall EU objective is expected to fall far short with existing policies. (European Environment Agency, 2018c)

Emissions from the ESD sector consists of more diverse range of activities and emission sources compared to emissions trading. According to (Forster, et al., 2012), building sector provides the biggest GHG reduction potential with negative cost which means that a certain reduction method also saves money. Such measures consist of retrofitting the building shell of existing buildings, upgrading the heat distribution systems and boilers as well as installing water-saving faucets. Changing the heating method to a heat pump can be cost-negative but only for larger buildings. Although the concept of negative cost might sound counterfactual, the phenomenon is commonly reported and arises typically from the information shortage or from the lack of investment capability (Boyce, 2018). Excessive reduction potential with a negative cost could also be seen as a malfunction of certain policies.

This chapter provides an insight to the European heating sector, focusing in particular to that part of the heating market which is currently not included in the EU ETS. This chapter also describes the taxation of natural gas and gasoil, the two predominant fuels used for heating of buildings.

4.1 Description of the heating sector

In order to study the feasibility of inclusion of the heating sector in the EU ETS, an analysis of the sector must be carried out. A comprehensive data set of the heating and cooling demand as well as of the source of the heating and cooling energy is provided by Heat Roadmap Europe (Heat Roadmap Europe, 2017), a consortium consisting of universities, research institutions, industry organizations and local authorities. The analysis carried out in this chapter is based on this data set, unless otherwise stated, and it describes the situation as of 2015.

The heating and cooling data are available separately for industry, residential and service sectors while the energy demand is divided between space heating, space cooling, process heating, process cooling, production of hot water and other heating. Most of the industry is already included in emission trading (European Commission, 2015) and thus, its analysis is beyond the scope of this theses. The same applies for heating and cooling demands by process heating and by process cooling which is why both of them are excluded. Rest of the heating and cooling energy is included in the analysis. Table 8 presents the delivered heating and cooling demands in residential and service sectors in the EU in 2015.

Table 8 Delivered heating and cooling demands in residential and service sector buildings in the EU in 2015 (Heat Roadmap Europe, 2017).

	Space heating	Hot water	Space cooling	Total
Residential sector	1 755 TWh	369 TWh	55 TWh	2 179 TWh
Service sector	728 TWh	72 TWh	130 TWh	930 TWh
Total	2 483 TWh	441 TWh	185 TWh	3 109 TWh

The delivered heating and cooling demands are dominated by space heating which accounts for 80 % of the total energy and 94 % when summed up with the delivered heat demand by hot water. The residential sector consumes around three quarters of the overall delivered energy demand. Delivered heating and cooling energy refers to the energy that has already been converted to either heat or cold. Another illustration would be to present the same values by the final energy demand which describes the energy input into the boiler. Table 9 presents the final energy demands in residential and service sector buildings in the EU in 2015.

Table 9 Final heating and cooling demands in residential and service sector buildings in the EU in 2015 (Heat Roadmap Europe, 2017).

	Space heating	Hot water	Space cooling	Other heating	Total
Residential sector	2 191 TWh	438 TWh	26 TWh	191 TWh	2 845 TWh
Service sector	858 TWh	84 TWh	45 TWh	-	987 TWh
Total	3 049 TWh	521 TWh	71 TWh	191 TWh	3 832 TWh

The final heating and cooling demand by service and residential sector buildings in the EU in 2015 was around 3 800 TWh. This accounts for 20 % of EU's 18 900 TWh gross inland energy consumption making it one of the greatest energy consumers in Europe (Eurostat, 2017). The average utilization rate of heat generation units in the EU can be determined as a difference between delivered energy demand and final energy demand and it is 81 %.

Majority of the heating and cooling demand of buildings is satisfied by fossil fuels. Natural gas, oil and coal together provide 63 % of the final energy demand. In reality, the proportion of fossil fuels used for heating and cooling purposes is even greater because a share of both electricity and district heating is produced by burning fossil fuels (Eurostat, 2018a). Figure 12 presents the final energy demand of buildings in the EU by energy carrier.

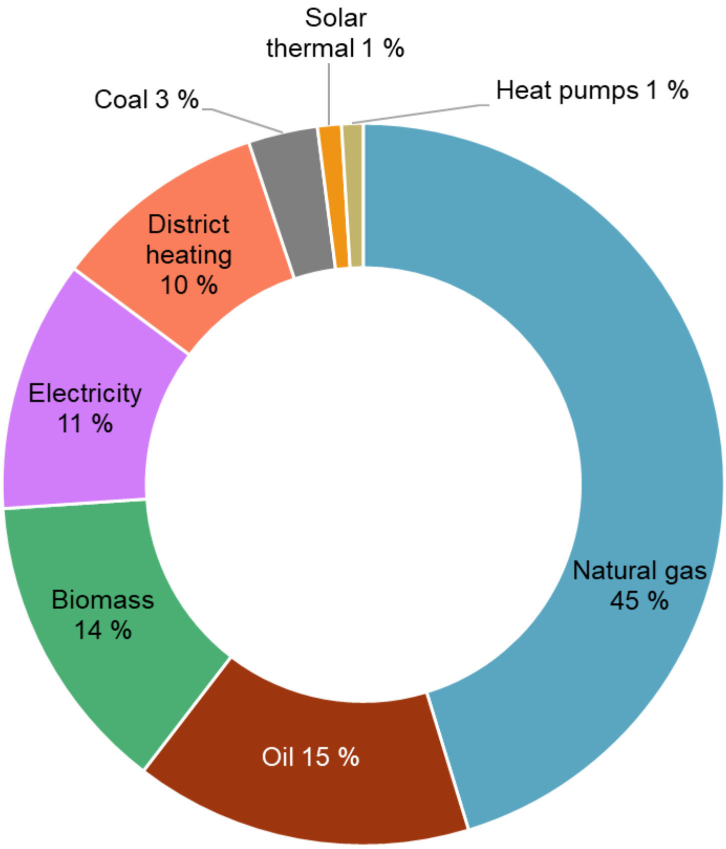

Figure 12 Final energy demand of buildings in the EU by energy carrier in 2015 (Heat Roadmap Europe, 2017).

Satisfying the heating and cooling demand of buildings produces considerable amount of GHG emissions. The heating sector alone is responsible for annual emissions worth around 540 Mt of CO_2-eqv. This amount consists of emissions from natural gas (350 Mt), oil (150 Mt) and coal (40 Mt). (Heat Roadmap Europe, 2017) Given the estimate by the (European Council, 2018) of a 630-megatonne overall carbon footprint of buildings in the EU, it is evident that heating and cooling by far are the biggest contributors when it comes to GHG emissions of buildings. Thus, a detailed analysis on the heating sector will provide comprehensive coverage on the overall GHG emissions caused by the building sector.

Determination whether a given energy carrier used for heating and cooling is included in the EU ETS depends on the fuel and on the technology used as well as on the size of installation. Renewable fuels are automatically excluded from emission trading regardless of the size of the combustion unit. All energy activities that use fossil fuels for the production of heat and electricity are included in emission trading if the thermal input of the combustion unit exceeds 20 MW. (European Commission, 2015) The following subsection briefly describes the energy carries used for heating and cooling of buildings and clarifies whether the given carrier is already included in EU ETS or not.

4.1.1 District heating

According to data derived from (Heat Roadmap Europe, 2017) the final heating demand by district heating to residential and service sector buildings in the EU was 370 TWh. It is worth noting that some references, such as (Connolly, et al., 2013) or (Werner, 2017) claim this value to be somewhat greater. This originates from the fact that there is no universal nor standardized definition for district heating and consequently the heat that is considered as district heating varies. On this thesis the definition provided by (Statistic Finland, 2018a) is used which states that only that derived heat which is used for space heating and to produce hot water is considered as district heating. Dissimilar to some other definitions, this will ignore the derived heat used for heating of industrial processes. Table 10 presents the sectoral distribution of district heating demand.

Table 10 Sectoral distribution of final energy demand of district heating in the EU in 2015 (Heat Roadmap Europe, 2017).

	Space heating	Hot water	Space cooling	Other heating	Total
District heating	313 TWh	56 TWh	-	1 TWh	370 TWh

A review carried out by (Werner, 2017) claims the number of district heating networks in Europe to be at around 6000 systems. The emission trading directive (2003/87/EC) determines that those combustion installations having a thermal input over 20 megawatts must participate in emission trading. The data of the share of the district heating systems that meet this threshold is hard to find or might not exists. According to (GreenStream, 2015) a great majority of district heating energy produced already falls under EU ETS, and thus its further examination is outside the scope of this thesis.

4.1.2 Electricity

The final heating and cooling energy demand of residential and service sector buildings by electric heating in the EU was 432 TWh. This value does not take into account the indirect heating caused by electrical appliances. Heat pumps consumed another 37 TWh electricity and produced 93 TWh of heat for space heating and for heating of hot water. Table 11 presents the sectoral distribution of electrical heating and cooling demand. The initial data is provided so that all space cooling is classified under direct electric and only heat produced by the heat pumps is classified under heat pumps.

Table 11 Sectoral distribution of final energy demand of electrical heating and cooling in the EU in 2015 (Heat Roadmap Europe, 2017).

	Space heating	Hot water	Space cooling	Other heating	Total
Direct electric	200 TWh	74 TWh	71 TWh	86 TWh	432 TWh
Heat pumps	32 TWh	5 TWh	-	-	37 TWh

According to (Eurostat, 2018a), around half of Europe's electricity production is based on combustible fuels, mostly coal and natural gas. A lion's share of this is produced in installations with rated thermal input over 20 megawatts (European Commission, 2015). Thus, inclusion of the heating sector in the EU ETS would have negligible, if any, effect on electricity production and consequently its further examination is outside the scope of this thesis.

4.1.3 Oil

The final heating energy demand of residential and service sector buildings by heating with oil and other petroleum products in the EU was 580 TWh. This makes oil the second most important source of energy on the heating sector with 15 % market share. Over 98 % of the oil is used for space heating and for heating of hot water. Table 12 presents the sectoral distribution of oil heating demand.

Table 12 Sectoral distribution of final energy demand of oil heating in the EU in 2015 (Heat Roadmap Europe, 2017). Numbers are rounded

	Space heating	Hot water	Space cooling	Other heating	Total
Oil	471 TWh	99 TWh	-	9 TWh	580 TWh

Oil and other petroleum products which are used for heating are consumed in small on-site and property-specific boilers on decentralized heating systems with over 20 million individual boilers found in Europe. (Connolly, et al., 2013). This makes oil an essential energy carrier with regards to the inclusion of the heating sector in the EU ETS. Therefore, oil heating is further examined in the upcoming chapter 4.2.

4.1.4 Natural gas

The final heating energy demand of residential and service sector buildings by heating with natural gas in the EU was 1 736 TWh. With its 45 % market share of the total heating market, natural gas is by far the most important source of energy on European heating sector. Approximately 95 % of the natural gas is used for space heating and for heating of hot water. Table 13 presents the sectoral distribution of natural gas heating demand.

Table 13 Sectoral distribution of final energy demand of gas heating in EU in 2015 (Heat Roadmap Europe, 2017). Numbers are rounded

	Space heating	Hot water	Space cooling	Other heating	Total
Natural gas	1 418 TWh	241 TWh	-	78 TWh	1 736 TWh

Similar to oil and other petroleum products, natural gas is consumed in small on-site and property-specific boilers on decentralized heating systems. According to (Connolly, et al., 2013) over 70 million such individual natural gas boilers can be found in the EU. This makes natural gas an essential energy carrier with regards to the inclusion of the heating sector in the EU ETS. Therefore, heating with natural gas is further examined in the upcoming chapter 4.2.

4.1.5 Others

The final heating energy demand of residential and service sector buildings by heating with biomass, coal and solar thermal altogether in the EU was 677 TWh and their combined market share reaches 18 %. Table 14 presents the sectoral distribution of heating demands of these three energy carriers.

Table 14 Sectoral distribution of final energy demand of biomass, coal and solar thermal heating in the EU in 2015 (Heat Roadmap Europe, 2017). Numbers are rounded.

	Space heating	Hot water	Space cooling	Other heating	Total
Biomass	480 TWh	21 TWh	-	16 TWh	518 TWh
Coal	111 TWh	7 TWh	-	-	119 TWh
Solar thermal	22 TWh	18 TWh	-	-	41 TWh

The amount of biomass tabulated above includes all types of biomass such as wood fuel, liquid biofuels and biogas. Since all these forms of biomass are considered renewable, inclusion of the heating sector in the EU ETS would have no direct effect for biomass-based heating. Similarly, nor would the solar thermal be affected for the same rationale. Consequently, both of them are outside the scope of this thesis and thus, excluded from further examination.

On the other hand, inclusion of the heating sector in the EU ETS would most likely affect coal in the same regard that it effected oil and natural gas. According to (European Commission, 2016) there are over 3 million decentralized and small on-site heating systems in Europe of which almost two-thirds are located in Poland. However, given the relatively moderate market share of 3 % as well as the expected gradual fade of this heating method (Connolly, et al., 2013), decentralized coal heating is excluded from further examination.

4.2 Analysis on non-ETS heating sector

As discussed in the previous chapter, inclusion of the heating sector in the EU ETS would have the greatest effect on small property-specific natural gas and oil boilers used in decentralized heating systems. There are over 100 million such units in the EU alone and natural gas boilers account for approximately 80 % of them. It has been estimated that over 90 % of these boilers are located in the residential buildings. (Connolly, et al., 2013; European Commission, 2016)

There are substantial differences between the European countries – both in the magnitude of consumption as well as in the heating profile. In order to assess the impact of inclusion of the heating sector in the EU ETS a throughout analysis of the heating boilers should be carried out. The following subsection provides such analysis including the age, size and location of the boilers as well as their energy use.

4.2.1 Boiler units

There are some 88 million gas boilers and 18 million oil boilers in the European Union. A great majority of these boilers have a thermal input below a 25-kilowatt threshold. Figure 13 presents the number of natural gas boilers and Figure 14 the number of oil boilers in the European Union divided into four size categories according to the thermal input. (European Commission, 2016)

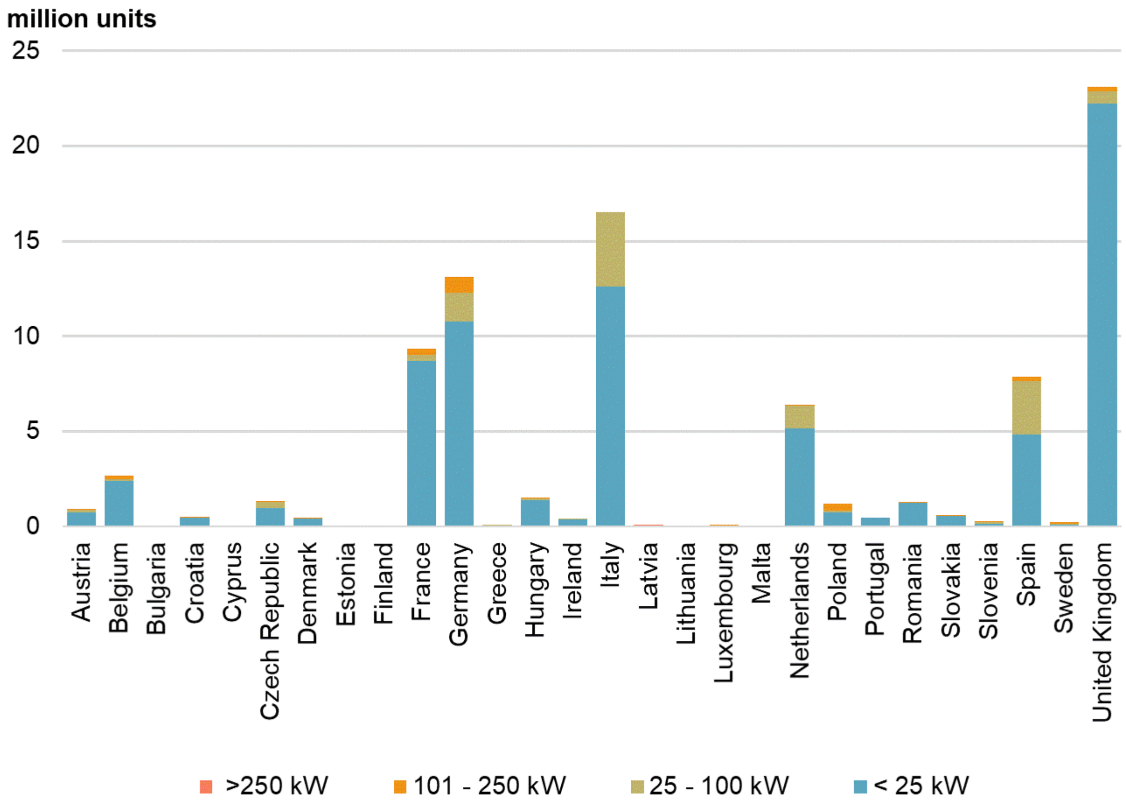

Figure 13 Number of natural gas boilers in the EU (European Commission, 2016).

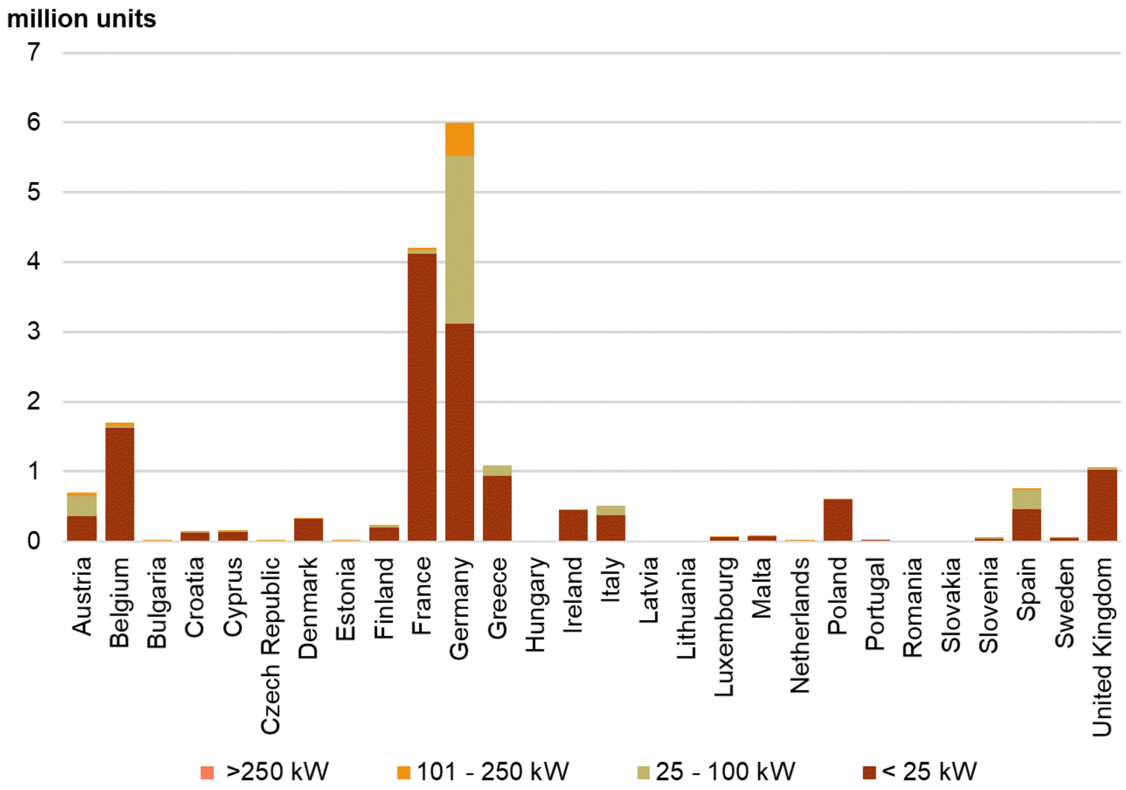

Figure 14 Number of oil burners in the EU (European Commission, 2016).

The largest stocks of natural gas boilers can be found in the most populous countries of the EU. United Kingdom (with 26 % share of the overall boiler stock) accommodates the largest number gas boilers and it is being followed by Italy (19 %), Germany (15 %), France (11 %) and Spain (9 %). In Cyprus, Finland and Malta there are no installed decentralized gas boilers and for Lithuania the data is not available. Pearson Correlation Coefficient (PCC) of 0,87 between the population and number of gas boilers indicates that there is relatively strong dependence between these two parameters. (World Bank, 2018b; European Commission, 2016)

The division of oil boilers between the countries is more heterogeneous with Germany (33 %) and France (23 %) dominating over half of the market. Latvia is the only country with no installed decentralized oil boilers and for Lithuania the data is not available. The correlation (PCC = 0,75) between the population and number of oil boilers is weaker than in the case of gas boilers, indicating that other factors than population play more important role. (World Bank, 2018b; European Commission, 2016)

Table 15 presents the overall stock of gas and oil boiler units in the Europe according to their thermal input as well as the relative share of a given size category. Most of these boiler units are rated with a thermal input below 25 kW and there is only little difference between the fuels. (European Commission, 2016)

Table 15 Number of gas and oil burner units according to their thermal input as well as the relative share of a given size category (European Commission, 2016).

	Gas boilers		Oil boilers	
	Amount	Percentage	Amount	Percentage
< 25 kW	74,64 milj.	84 %	14,11 milj.	78 %
25 - 100 kW	11,26 milj.	13 %	3,40 milj.	19 %
101 - 250 kW	2,44 milj.	3 %	0,69 milj.	4 %
> 250 kW	380	0 %	0	0 %
Total	88,34 milj.		18,20 milj.	

As discussed earlier, countries with large population tend to have more boilers than countries with small population. However, as the PCC between the population and number of boilers is not within a negligible range from one, the population of a country cannot alone the explain the distribution of boilers by country. Perhaps a more descriptive measure indicating the significance of these boilers for a given country is the number of boilers per capita. This measure would also indicate the magnitude of effect of inclusion of the heating sector in the EU ETS for a given country. Table 16 presents the number of gas boilers per 1000 residents in all 28 member states of the EU in descending order while Table 17 presents the corresponding figures for oil boilers.

Table 16 Number of gas boilers per 1000 residents in all member states of the EU in descending order (European Commission, 2016; World Bank, 2018b).

Rank	Country	Boilers per 1000 residents	Rank	Country	Boilers per 1000 residents	Rank	Country	Boilers per 1000 residents
1	Netherlands	373	11	Slovenia	116	21	Latvia	19
2	United Kingdom	350	12	Luxembourg	108	22	Greece	10
3	Italy	273	13	Austria	106	23	Estonia	6
4	Belgium	236	14	Slovakia	104	24	Bulgaria	2
5	Spain	169	15	Ireland	82	25	Lithuania	Not available
6	Germany	158	16	Denmark	74	26	Cyprus	0
7	Hungary	150	17	Romania	65	26	Finland	0
8	France	140	18	Portugal	45	26	Malta	0
9	Czech Republic	129	19	Poland	32			
10	Croatia	119	20	Sweden	24			

Table 17 Number of oil boilers per 1000 residents in all member states of the EU in descending order (European Commission, 2016; World Bank, 2018b).

Rank	Country	Boilers per 1000 residents	Rank	Country	Boilers per 1000 residents	Rank	Country	Boilers per 1000 residents
1	Belgium	149	**11**	Finland	41	**21**	Czech Republic	1
2	Malta	148	**12**	Croatia	34	**22**	Bulgaria	1
3	Cyprus	123	**13**	Slovenia	26	**23**	Netherlands	0
4	Luxembourg	106	**14**	Spain	16	**24**	Hungary	0
5	Greece	101	**15**	United Kingdom	16	**25**	Slovakia	0
6	Ireland	92	**16**	Poland	16	**26**	Romania	0
7	Austria	80	**17**	Italy	8	**27**	Lithuania	Not available
8	Germany	73	**18**	Sweden	5	**27**	Latvia	0
9	France	63	**19**	Estonia	3			
10	Denmark	57	**20**	Portugal	2			

The tables demonstrate a significant range in boilers per capita between the countries. For both fuels there are several counties with negligible boiler stock. On the other hand, the highest values for boilers per capita indicate that these units are crucial for the heating sector of a given country. Of the 27 countries with available data only five have larger amount of decentralized oil boilers than decentralized gas boilers: Cyprus, Finland, Greece, Ireland and Malta. (European Commission, 2016)

It is noteworthy that countries for whom gas is an important energy source are oftentimes different than the ones for whom oil is important. There is insignificant correlation between gas boilers per capita and oil boilers per capita (PCC = -0,13) as well as between the country ranks (PCC = 0,03) of these lists. Thus, referring simply to “gas and oil countries” regarding the European heating sector can be misleading.

Another research question would be to study the possible dependence between number of boilers per capita and GDP per capita of a country. Higher GDP indicates better investment capabilities and thus more investments towards emission reductions can be expected. Since these investments would be made by private individuals as opposed to companies, the GDP must be normalized according to Purchasing Power Parity (PPP) and presented on per capita basis.

An analysis was carried out and it shows very small positive correlation (PCC = 0,22) between GDP_{PPP} and gas boilers per capita. The dependence is considerably higher between oil boilers per capita and GDP_{PPP} (PCC = 0,44); however, even this value does not represent particularly significant correlation. The total number of both gas and oil boilers per capita combined has similar (PCC = 0,41) correlation. (Eurostat, 2018b; European Commission,

2016) The analysis shows that in average countries with high GDP_{PPP} tend to have more individual and decentralized on-site gas and boilers. However, the correlation is too weak for drawing unambiguous conclusions.

Another standpoint for describing the existing stock of decentralized and small property-specific boilers is to consider the age of the units. Figure 15 presents the age distribution of installed gas boilers and oil boilers in the EU divided into three age groups.

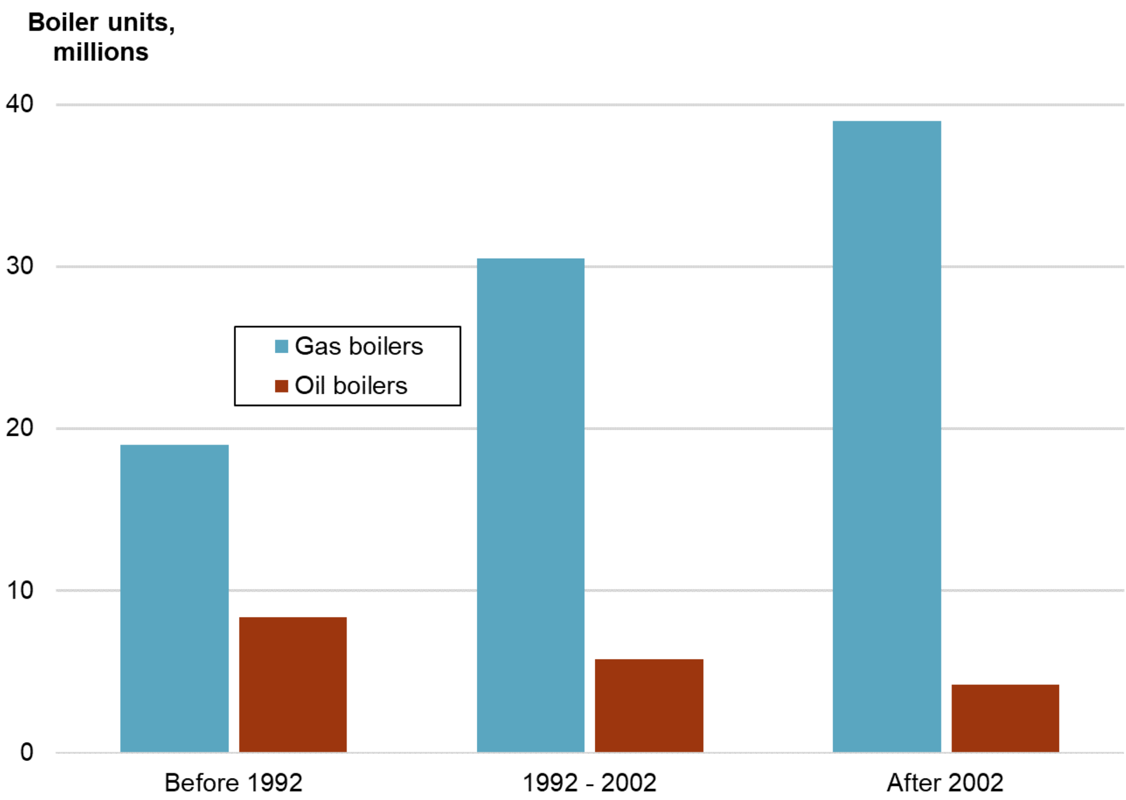

Figure 15 Age distribution of installed gas boilers and oil boilers in EU (European Commission, 2016).

The data reveals substantial differences between the age distributions of boiler stocks. While only 20 % of the gas boiler stock has been installed before 1992, almost half of the oil boilers belong to the oldest age group. When the most recent age category is being reviewed, the proportions turn upside down. About one third of the boilers belong to the middlemost age group and have been installed between the years 1992 and 2002. (European Commission, 2016)

From the figure it can be concluded that the role of oil boilers is gradually decreasing with an aging boiler stock. On the other hand, gas boilers are becoming increasingly important with more installations carried out in recent years. Older stock of oil boilers suggests that these units are closer towards the end of their lifetime and hacing lower residual value, both of which indicate the replacement of oil boilers in the coming years.

4.2.2 Energy use

The gas and oil used in the European heating sector is most commonly used in decentralized boilers with a thermal input below 25 kW (European Commission, 2016). Thermal efficiencies of these boilers range from below 80 % of the several-decade-old oil boilers to 105 % of the cutting-edge condensing boilers using both gas and oil. (Martinopoulos, et al., 2018) Figure 16 presents the final energy demand of oil and gas used for space heating, heating of hot water, and other heating in residential and service sector buildings in all 28 countries of the EU.

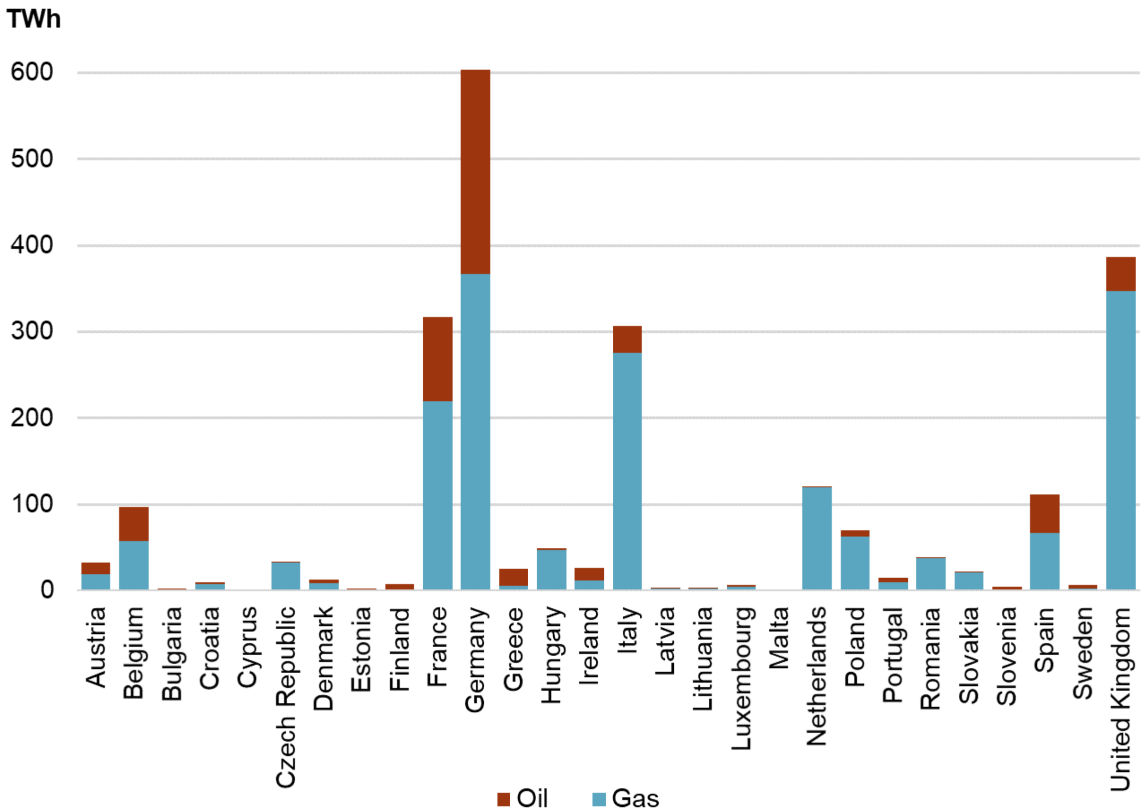

Figure 16 Final energy demand of gas and oil used for space heating, heating of hot water and other heating in residential and service sector buildings in all 28 countries of the EU (Heat Roadmap Europe, 2017).

The final energy demand of oil and gas used for heating of residential and service sector buildings was 2 320 TWh and the delivered energy demand 1810 TWh. The data sequence of “other heating” is missing from the delivered energy demand side which is why the sequence is subtracted also from the final energy side for the use of the following calculations on the utilization rate. The overall amount of subtracted energy from final energy demand was 87 TWh. (Heat Roadmap Europe, 2017)

The average utilization rate for gas boilers in the Europe is 82 % ranging from 71 % in Croatia to 87 % in France. The average utilization rate for oil boilers is 78 % and it ranges from 72 % in Croatia to 84 % in Lithuania. (Heat Roadmap Europe, 2017) Slightly better utilization rate of gas boilers is in line with the review carried out by (Martinopoulos, et al., 2018).

Since there are considerable differences in population between the member states of the EU, rather than using the final energy demand in absolute terms the demand per capita would more reasonable measure. Besides the population, final energy demand of a country is strongly influenced by local weather conditions. Thus, the heating demand is manipulated by using the heating degree day of an individual country and normalizing this this value towards the average heating degree day in the EU. This manipulation is applied to space heating and other heating but not for the heating of hot water as the latter is scarcely influenced by local weather conditions. Both fuels were normalized separately. Figure 17 presents the normalized final energy demand of gas and oil used for space heating, heating of hot water and other heating in residential and service sector buildings.

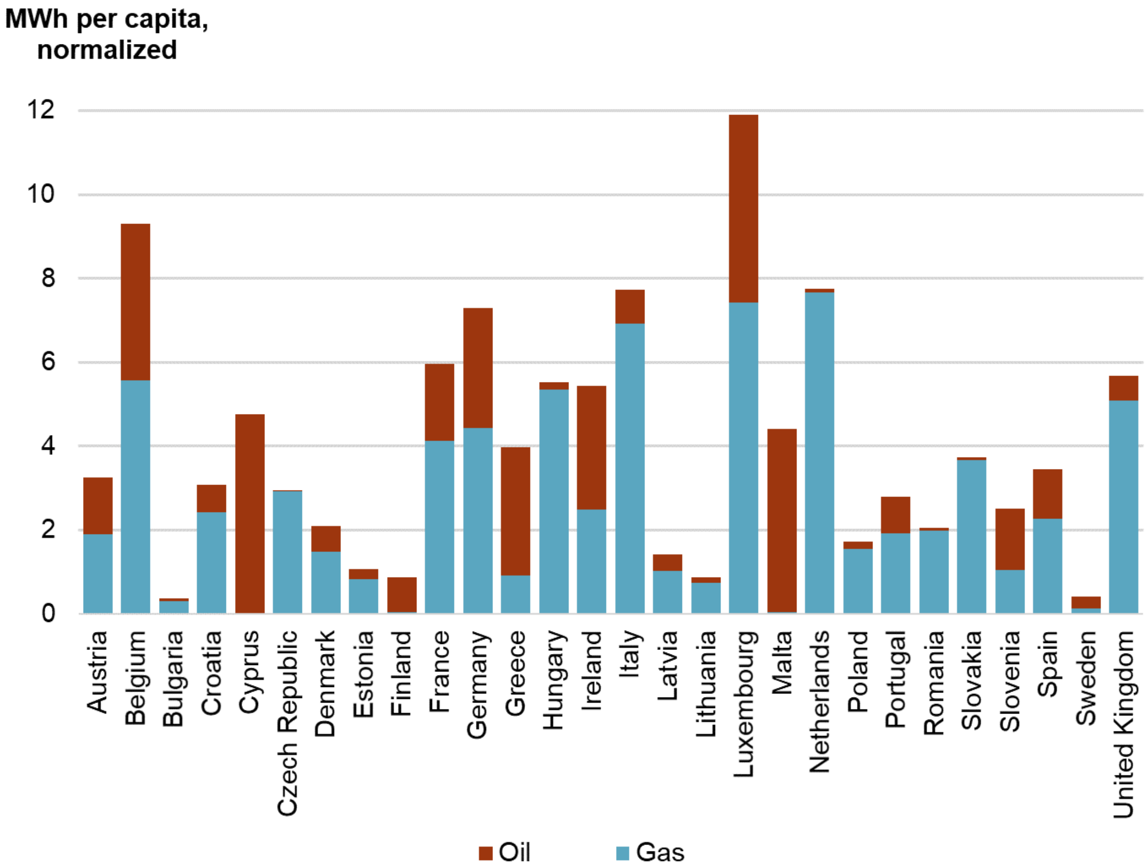

Figure 17 Normalized final energy demand per capita of gas and oil used for space heating, heating of hot water and other heating in residential and service sector buildings in all 28 countries of the EU (Heat Roadmap Europe, 2017; World Bank, 2018b).

The figure describes the importance of gas and oil in heating irrespective from local weather conditions. It does not; however, illustrate the energy efficiency of buildings due to the differences in energy portfolios of countries.

4.3 Description of the building stock

The building stock in Europe is dominated by residential sector buildings which consist 76 % of the overall building floor area. Existing stock is rather heterogeneous: residential building's share of the overall building floor area varies from nearly 90 % in Italy to around 60 % in Slovakia. There are also considerable differences in the average ages of the building stock. Figure 18 presents the age distribution of the residential building stock in the EU in 2014. The data was not available for non-residential buildings nor for Austria. (European Commission, 2018d)

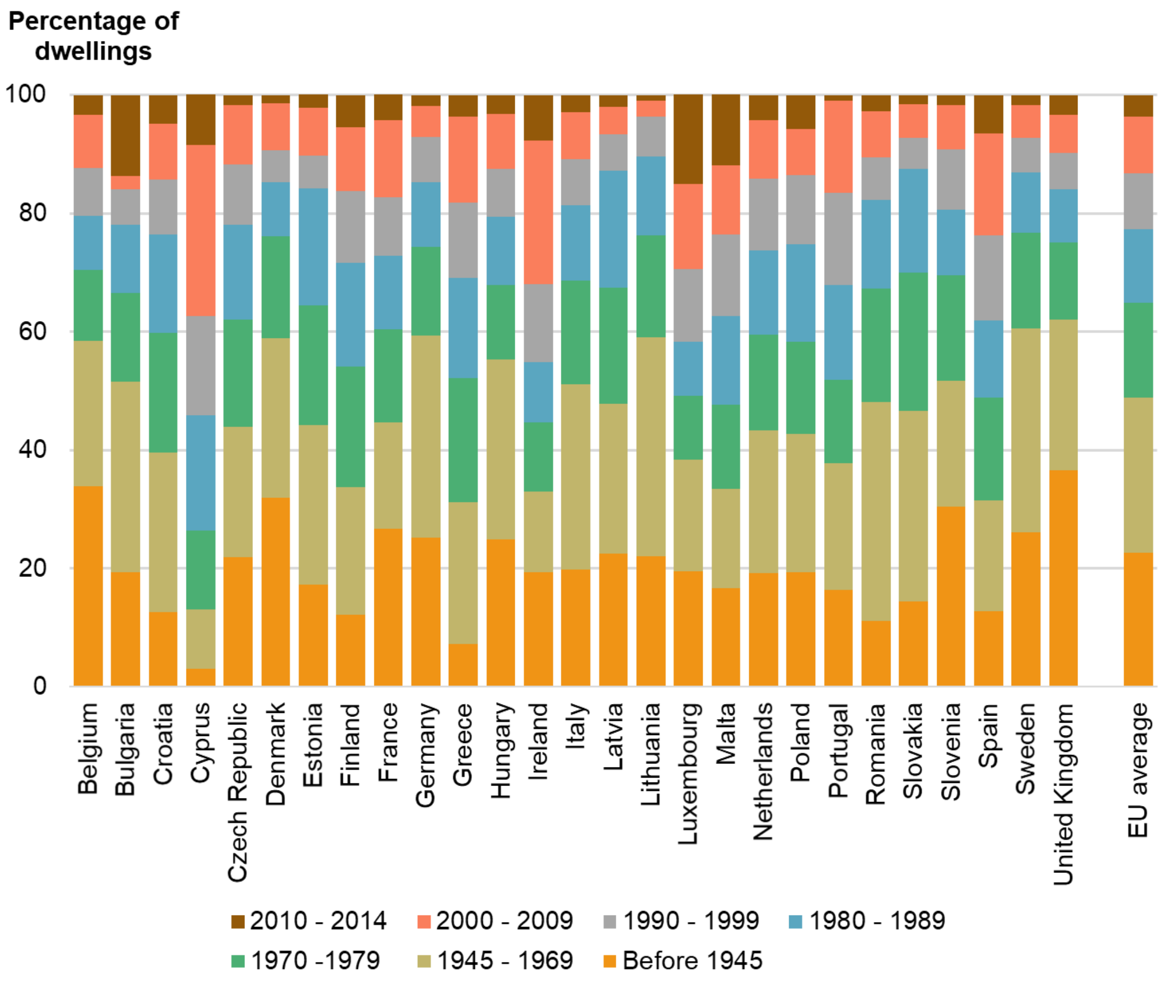

Figure 18 Age distribution of dwellings in the EU (European Commission, 2018d).

European dwelling stock is rather old: approximately half of the buildings have been constructed before the 1970s. Most recent building stock can be found in Cyprus where over a third of the dwellings have been built during this millennium. Also Ireland, Luxembourg, Malta and Spain have over 20 % of their stock being built after 2000. On the contrary, in Belgium, Denmark, Germany, Lithuania, Sweden and the United Kingdom around 60 % of dwellings have been built before the 1970s. The annual construction rate in the EU has steadily decreased since the 1970s and stands currently at 0,7 % of the total building stock. (European Commission, 2018d)

The age distribution is an important feature regarding the energy consumption of buildings because the energy efficiency has improved significantly over the decades. This development has further accelerated in recent years and the rapid transformation can be tracked down to the implemented regulations concerning the energy efficiency of buildings. Although some individual countries have had their own set of regulations since the 1970s, it was not until 2002 when the first European-wide thermal standards were introduced. A typical building constructed after 2010 is over twice as much energy-efficient than corresponding building from the 1990s and quadruple more efficient than from the 1950s. Figure 19 presents the U-values (describing heat losses) of the European building stock according to the year of construction as well as proportional shares of the overall building stock. (Fokaides, et al., 2017; European Commission, 2018d)

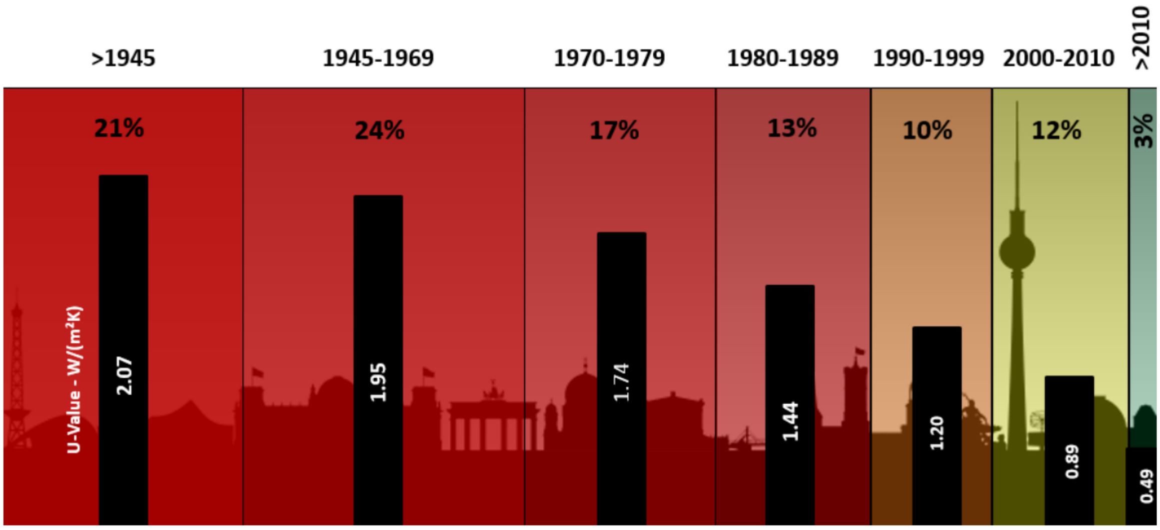

Figure 19 Average U-values within the European building stock according to the year of construction. Data: (European Commission, 2018d), data visualization: (Buildings Performance Institute Europe).

Currently the main regulations governing the energy use of buildings are the energy efficiency directive (2012/27/EU) and the energy performance of buildings directive (2010/31/EU), latter one having amended in 2018 (2018/844/EU). The main objective of this basket of regulations is to help decarbonizing the building stock by 2050. This is done by the means of promoting smart technologies, creating national standards for energy performance certificates and boosting energy efficient renovations. From the figure above it can be seen that the implemented energy efficiency policies have indeed succeeded to significantly improve the energy performance of modern buildings. (European Commission, 2018d)

Given the low annual construction rate; however, the energy efficiency policies targeted towards modern buildings have had only limited effect towards the average energy performance of the building stock. Besides regulating new constructions, another important standpoint regarding energy efficiency improvements is the rate of which old buildings are being renovated. Old buildings going through major renovations also fall under contemporary energy efficiency regulations and thus, accelerating the annual renovation rate will increase the average energy performance of the building stock. Nowadays 1,2 % of the building stock is being renovated each year, trailing far behind the EU's objective of 2-3 %. Current renovation rate means that upgrading the whole building stock to meet the present-day standards would not be completed until the end of the century. (Sesana & Salvalai, 2018; Artola, et al., 2016)

The annual demolition rate is estimated to be around 0,1 % of the overall building stock. Such rate is negligible compared to renovation and construction rates and consequently implies that the impact of demolitions towards the overall energy efficiency improvements is insignificant. Furthermore, slow demolition rate suggests that great majority of the present building stock will continue to exist far beyond 2050, amplifying the need to accelerate the renovation rate. (Artola, et al., 2016)

Spencer, et al., 2017 analyzed the European heating data and found out that the aggregated energy intensity in the residential building sector decreased by 2,0 % per year between 2000 and 2010 and by 1,3 % during 2010-2013. EU's commitment to reduce its ESD sector GHG emissions by 30 % until 2030 compared to 2005 levels translates into annual linear reduction rate of 2,2 % during 2020-2030 (Babonneau, et al., 2018). Although the emissions from the building sector have been steady decreasing since the 1990, the slope has historically been far from the needed -2,2 % (European Environment Agency, 2018c). Given these considerations, it is evident that the current contribution by the building sector to the ESD sector's reduction targets falls far short.

4.4 Fuel taxation in Europe

Taxation of energy products is an important source of revenue for all member states of the European Union as can be illustrated from Figure 20. Energy products are being taxed by imposing excise duties on different types of fuels and electricity. Aforementioned tax segment is particularly important for Bulgaria, Estonia, Romania and Slovenia, all of which gain over 7 per cent of their total tax revenues from energy products while the importance is less significant for Belgium and France, both receiving less than 3 per cent from their tax revenues from energy products. (European Commission, 2019)

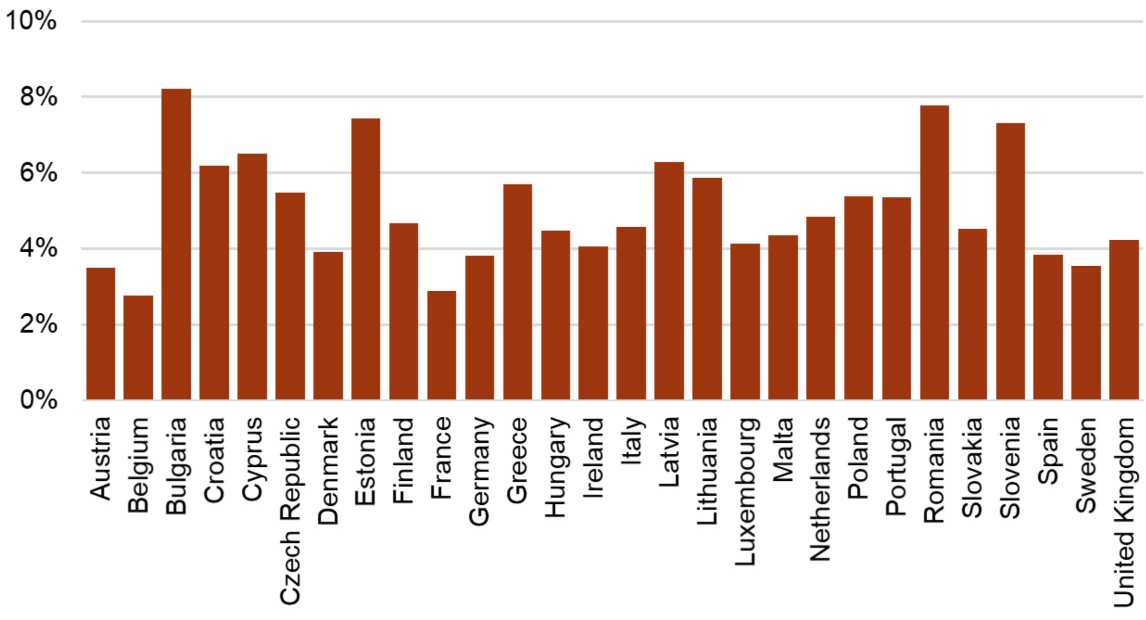

Figure 20 Share of tax revenues coming from taxation of energy products and electricity. The category covers all fuels, including transportation. (European Commission, 2019)

In addition to fiscal aspects, taxation can be used as an instrument to encourage towards environmental practices. European-wide carbon tax has been unsuccessfully proposed twice by the commission for this purpose. The foremost attempt took place long before the implementation of the EU ETS back in 1992 and its realization was expected to be difficult from the outset as adopting any fiscal measures into EU legislation will always require unanimity. The proposal faced opposition both from the industry lobbies as well as from certain member states who feared that their sovereignty would be compromised. Eventually certain degree of harmonization was achieved with regard to minimum levels of excise duties for energy products. Nonetheless, mandatory inclusion of a carbon component or any other feature related to greenhouse gases into taxation was not accomplished. (Ellerman, et al., 2010)

The European Union directive on taxation of energy products and electricity (2003/96/EC) was adopted in 2003 after a decade of intricate negotiations. Although the directive is characterized by unambitious minimum taxation levels and several exemptions, it managed to determine minimum excise tax rates for fuels and electricity. Minimum taxation levels vary depending on the sector and typically private businesses are eligible for reduced taxation. Countries are entitled to impose higher tax rates than the bare minimum and a great majority has decided to do so. There is also a wide spectrum of units in which the minimum rates are provided, hampering their comparison. (Hasselknippe & Christiansen, 2003) Minimum tax rates for the most commonly used fuels for heating purposes in their original units as set by the directive as well as their conversion to euros per a ton of carbon dioxide are presented below in Table 18. The presented tax levels are imposed for non-business use which is the category where a typical household would fall into. The conversion was carried out by using the parameters in “Fuel classification 2018” file provided by (Statistics Finland, 2018b).

Table 18 Minimum taxation levels of natural gas and gasoil, two predominant fuels used for heating in the European Union (2003/96/EC).

	Initial value from the directive	Value in €/t-CO_2
Natural gas	0,30 €/GJ	5,42
Gasoil	21 €/1000 litres	7,91

The second attempt to introduce a carbon component into EU legislation arose with the proposal to revise the existing energy taxation directive in 2011. This proposal strove to address tightened energy and climate goals by placing the spotlight on the carbon content of the fuel. Existing excise duties were to be torn down and divided between energy and carbon components. Energy component would be normalized according to the energy content of the fuel rather than volume, eliminating the current disfavor of renewable fuels characterized by low energy density. Furthermore, energy-based taxation would reward form energy efficient use of fuels. (Schlegel, 2014; European Commission, 2011)

The proposed carbon component would be based directly on the emission factor of the fuel, incentivizing the use low-carbon fuels and thus, reducing the GHG emissions. The commission suggested a minimum carbon tax of 20 €/t-CO_2 to be levied on most economic sectors. Direct CO_2 emissions from biofuel consumption were to be exempted from the carbon tax. Almost all fuel consumption was planned to be subject to energy tax while carbon component would be applicable only to non-ETS sectors. This would avoid double taxation of carbon dioxide as well as prevent competitive distortions between the ETS and non-ETS sectors. (Schlegel, 2014; Kari, et al., 2018)

Ultimately, also the second attempt to introduce mandatory CO_2 component failed due to strong opposition and the proposal was withdrawn in 2015. The original directive from 2003 imposing modest minimum rates still remains in force as of February 2019. (Kari, et al., 2018) Despite the directive does not obligate member states to implement the CO_2 tax, six countries have decided to introduce such component into their national taxation. In addition to the carbon component, there is a great variety of other tax components in the national taxation of the member states. Figure 21 presents the taxation of natural gas in the European Union and Figure 22 describes the corresponding for gasoil. Figures describe the situation at the beginning of 2018. (European Commission, 2019)

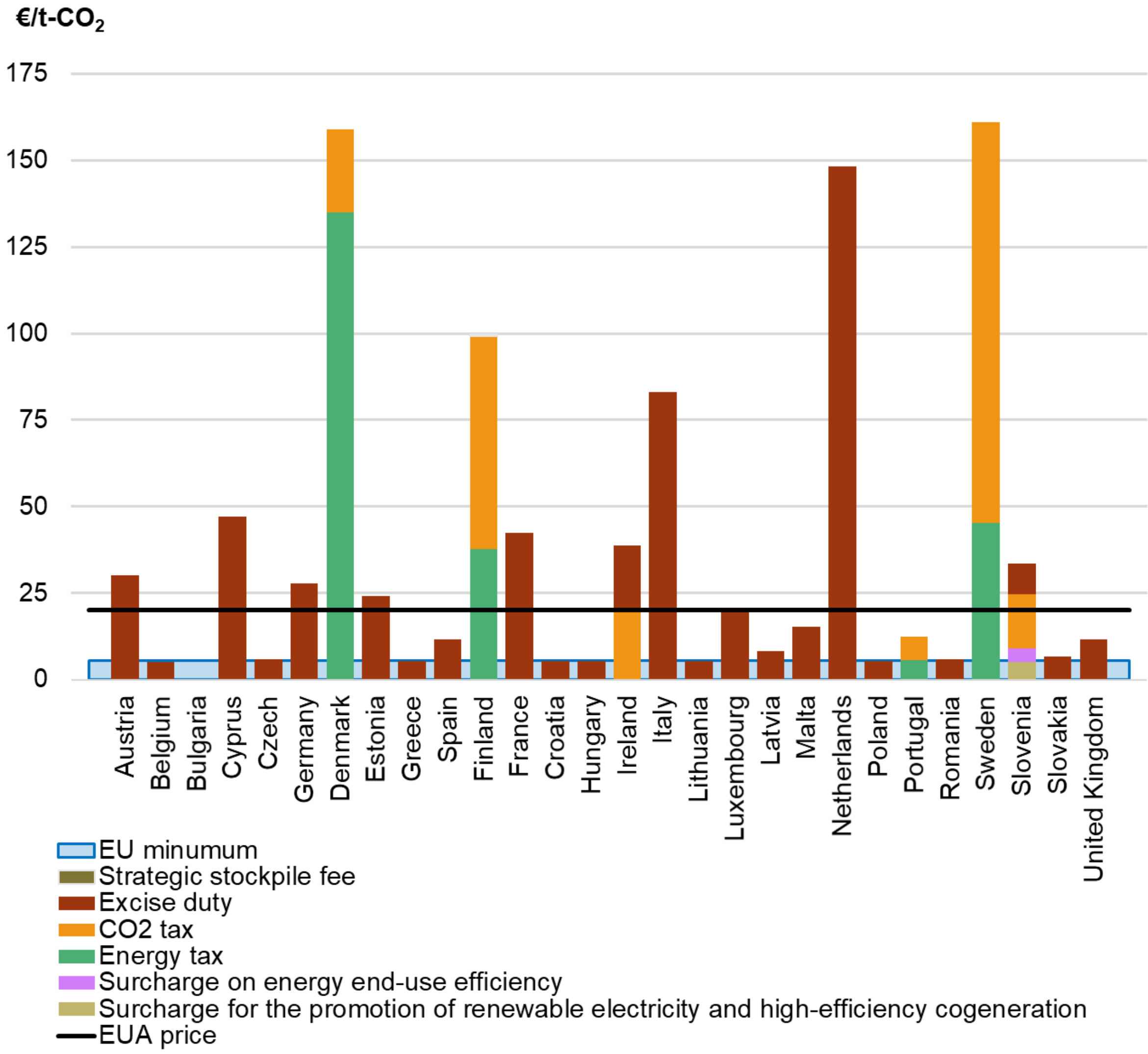

Figure 21 Taxation of natural gas for non-business users in the European Union. The segment currently falls outside the scope of the EU ETS. (European Commission, 2019; European Energy Exchange, 2019)

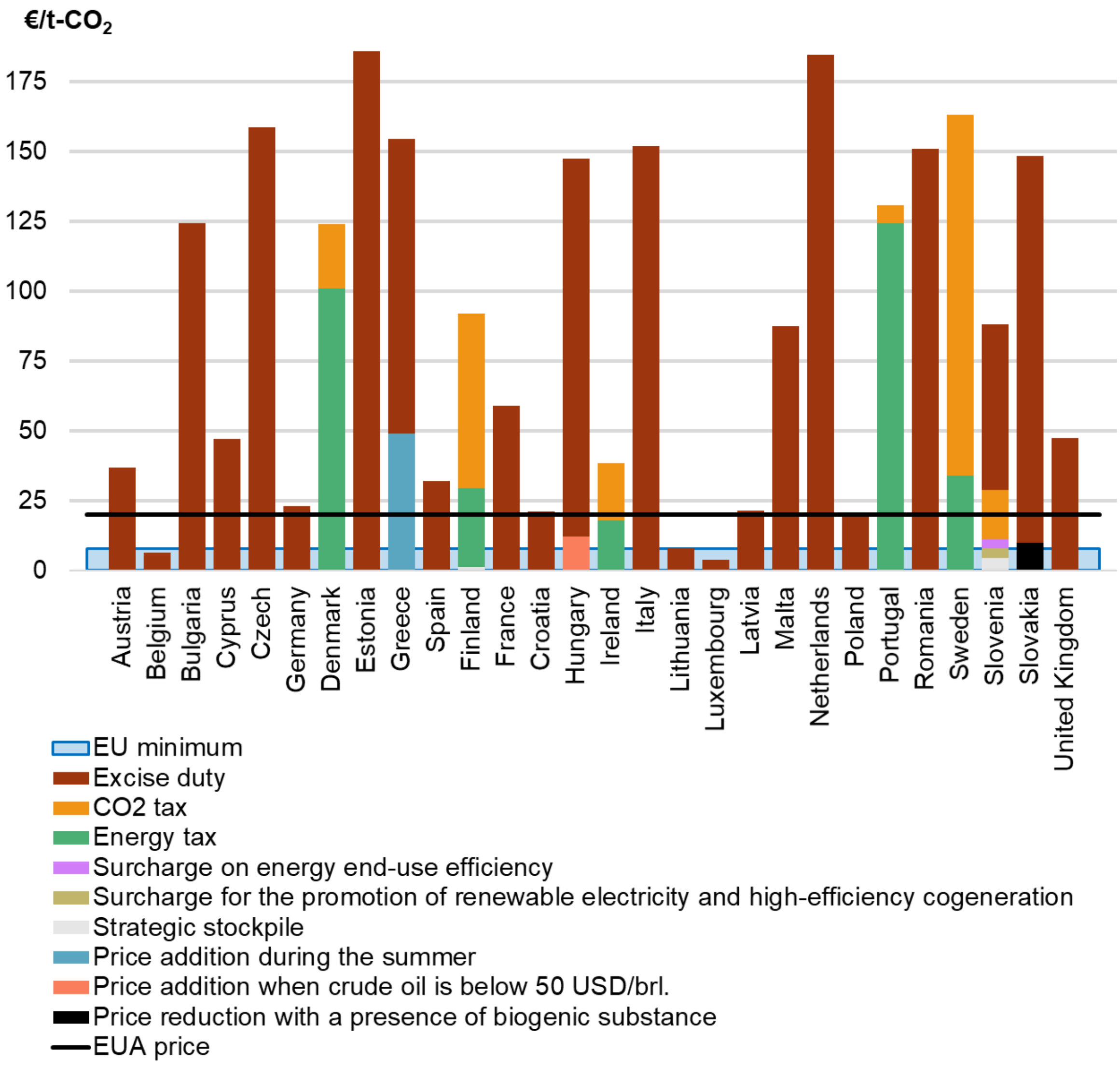

Figure 22 Taxation of gasoil for non-business users in the European Union. The segment currently falls outside the scope of EU ETS. (European Commission, 2019; European Energy Exchange, 2019)

Figures illustrate extensive differences in the harshness of fuel taxation between member states. The components from which the overall rate consists of has a wide variety with 9 different types components being used. Six countries; Denmark, Finland, Ireland, Portugal, Sweden and Slovenia; have divided their energy taxes into carbon and energy components, in accordance with the earlier proposal to revise energy taxation. (European Commission, 2019) This division does not; however, necessarily reflect commission's most recent proposal as some of the components had been introduced back in the 1990s (Schlegel, 2014).

Consumption-weighed and arithmetic average tax rates for natural gas are 40,0 €/t-CO_2 and 35,9 €/t-CO_2, respectively with a range variating from 0 €/t-CO_2 in Bulgaria to 161 €/t-CO_2 in Sweden. Consumption-weighted and arithmetic average tax rates for gasoil are 47,5 €/t-CO_2 and 87,7 €/t-CO_2, respectively with a range variating from 4 €/t-CO_2 in Luxembourg to 186 €/t-CO_2 in Estonia. The pronounced difference between the averages in gasoil taxation is largely due to Germany's low tax rates, a country responsible for nearly half of the consumption of heating gasoil in Europe. There seems to be no clear correlation (PCC <

|0,3|) between the tax rates and the GDP_{PPP} of the country for neither of the fuels. (European Commission, 2019)

Countries with high levels of natural gas taxation are often the same ones having the carbon tax in place. Conversely, similar correlation does not exist for gasoil. It is noteworthy that taxation levels for natural gas in Belgium and Bulgaria are lower than the minimum rate set by the taxation directive. In the case of gasoil, both Belgium and Luxembourg have levied rates lower than the directive would require. (European Commission, 2019)

Average tax rates for fuels used in non-ETS heating sector are approximately twice as high compared to the EUA price (European Energy Exchange, 2019). According to emission trading fundamentals; however, the considerable distinctions between countries' fuel taxation will not direct the emission reduction investments to where they are the cheapest and thus, the overall cost of emission reductions is far from being minimized (Haites & Yamin, 2004). On the other hand, cost-efficiency is not the sole determinant when tax strategies are being designed, as can be inferred from Figure 20.

4.5 Evaluating the Control Effect of Expanding the Scope of EU ETS

Another perspective regarding the inclusion of the heating sector in the EU ETS is the evaluation of its control effect as opposed to fuel taxation. Although European-wide carbon tax has been rejected twice (Kari, et al., 2018), it still stands as an alternative for expanding the scope of emission trading. Marginal Abatement Cost Curve (MACC) is an estimation tool for evaluating the differences between sectors' marginal abatement costs and Figure 23 presents an example of such curve (Kesicki, 2011). While the curves are generalizations, location-specific and should not be taken literary, MACCs with similar order and values have been reported elsewhere, such as the one published by (McKinsey&Company, 2010).

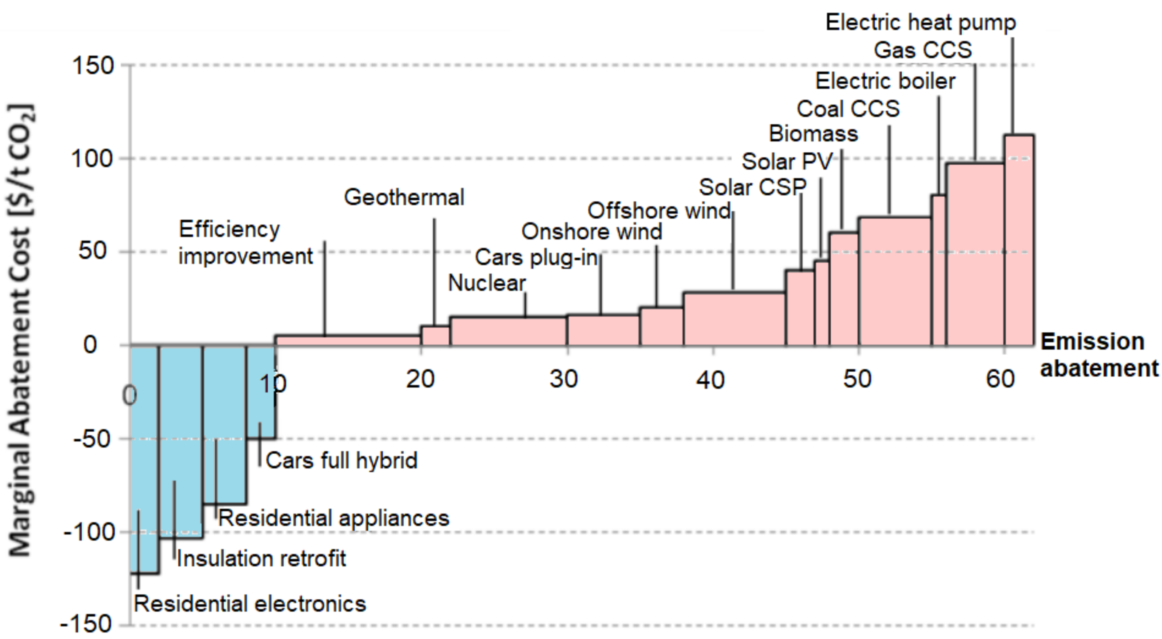

Figure 23 Example of an expert-based greenhouse gas marginal abatement curve (Kesicki, 2011). Modified by the author

The sectors, measures and technologies found on the left hand side of the curve are estimated to provide better potential of cost-efficient emission reductions compared to the sectors on the right. MACCs typically place residential sector measures into the leftmost side of the curve. These practices are frequently estimated to provide significant potential of reduction opportunities with negative cost. The existence of a negative marginal cost can be argued with the lack of information as well as with excessive upfront payments coupled with long payback periods. (Kesicki, 2011)

Table 19 Building sector's estimated abatement potential in 2020 divided into four cost bands. The numbers are given in megatons of CO_2-eqv. (Forster, et al., 2012)

Country	Overall remaining potential	Cost band < 0 €	Cost band 0-25 €	Cost band 25-50 €	Cost band > 50 €
Austria	1,46	0,90	0,01	0,01	0,55
Belgium	6,40	5,26	0,22	0,01	0,92
Bulgaria	0,75	0,55	0,01	0,01	0,18
Cyprus	0,15	0,07	0,01	0,01	0,07
Czech Republic	2,26	1,62	0,11	0,01	0,53
Denmark	0,82	0,24	0,01	0	0,57
Estonia	0,04	0,02	0	0	0,02
Finland	0,79	0,38	0,05	0,02	0,34
France	15,22	10,07	0,16	0,48	4,51
Germany	23,21	16,30	0,17	0,68	6,06
Greece	2,05	1,41	0,15	0,02	0,48
Hungary	1,19	0,67	0,05	0	0,48
Ireland	2,83	2,29	0,02	0,07	0,45
Italy	12,15	8,01	1,11	0,07	2,96
Latvia	0,36	0,29	0,01	0	0,06
Lithuania	0,50	0,40	0,01	0	0,09
Luxembourg	0,21	0,17	0	0	0,04
Malta	0,05	0,03	0	0,01	0,01
Netherlands	6,91	5,24	0,04	0,02	1,61
Poland	10,7	8,57	0,07	0,02	2,04
Portugal	1,01	0,25	0,11	0,05	0,61
Romania	0,30	0	0	0	0,30
Slovakia	0,44	0,29	0,02	0	0,13
Slovenia	0,19	0,11	0	0,01	0,08
Spain	10,94	8,33	0,78	0,09	1,75
Sweden	0	0	0	0	0
United Kingdom	17,15	12,28	0,56	0,04	4,27
Total	**118,06**	**83,72**	**3,65**	**1,62**	**29,08**

Table 19 presents building sector's estimated abatement potential in 2020 divided into four cost bands. It is notable that such models are highly sensitive on initial assumptions and even small differences in input values can have large impacts on the end result. This model uses a discount rate of 4 % and excludes energy taxation's share from the energy savings. GHG emissions from the use of electricity and its saving potential are not included in these numbers nor is district heating as these sectors both already fall under the scope of EU ETS. The data was not available for Croatia as the country was not part of the European Union at the time of the modeling. (Forster, et al., 2012)

Approximately 70 % of the 118 megaton abatement potential is estimated to be cost-effective. With a current price of EUA imposed into the building sector, this figure would increase to nearly 75 %. Germany (16 Mt CO_2-eqv), United Kingdom (12 Mt CO_2-eqv) and France (10 Mt CO_2-eqv) have the greatest abatement potential with a negative cost. In relative terms, the following countries have over 80 % of their abatement potential with a negative cost: Belgium, Ireland, Latvia, Luxembourg and Poland. On the other hand, the share of negative costs from the overall potential is below 50 % in Cyprus, Denmark, Estonia, Finland, Portugal and Romania. Nonexistent potential by Sweden can be justified by its building standards as well as by the large proportions of electricity and district heat. (Forster, et al., 2012)

A research report by (U.S. Energy Information Administration, 2014) studied the price elasticity of demand for heating fuels and for electricity. The study found out that the demand response is slightly stronger in the commercial building sector than in the residential building sector on the short run and significantly stronger in the long run. Subsequent study by (Burke & Abayasekara, 2017) confirmed these results and added that the demand response is even stronger for the industrial sector.

Above-mentioned considerations reflect that commercial and industry sectors operate more efficiently than the residential sector. ETS sectors have currently no incentive to participate in the non-ETS heating sector despite the MAC is lower than the current price of carbon within the emission trading system. Placing these actors into the same carbon market could unleash the residential sector's abatement potential with the capital and efficiency of the private sector.

A report by (OECD, 2018) found out that an increase in energy or carbon tax causes stronger demand response compared to the identical increase in the market price. Inclusion of the heating sector would certainly receive extensive visibility, suggesting that the involvement of the residential sector itself will be increased.

5 Heating sector in other emission trading systems

Although the European Union emissions trading system is the first major and the biggest emission trading system at the moment it is by no means the only one. The amount of emission trading systems has been steadily increasing as more and more countries and regional alliances seek for cost-effective ways to reduce their emissions. These systems are located in a vast range of geographical locations and are characterized by a variety of sectoral coverages, market sizes, reduction targets and operational principles. There are operational systems in four continents: North America, Europe, Asia and Oceania in addition to which implementation of the ETS is under consideration within a few South American countries. (International Carbon Action Partnership, 2019)

The purpose of this section is to concisely study these other existing emission trading systems and to introduce their main parameters. The focus is in particular to investigate whether the heating sector is already included in another system besides the EU ETS. This could provide valuable information regarding the inclusion of the heating sector in the EU ETS as some of the issues related to the topic might have already been solved.

5.1 Emission trading systems globally

The credibility of the existing emission trading schemes ranges from system to another. Some have just commenced and are going through a pilot phase with a plethora allowances allocated for free. Others have been around for more than a decade and have already gone through several structural reforms. The share of total emissions covered by emission trading varies from only a single sector with minimal coverage to nearly a full coating of all economic sectors. (International Carbon Action Partnership, 2019)

Profound research on all emission trading systems is outside the scope of this thesis. However, functionality of the scheme can be extrapolated by looking at the main parameters of the scheme. Severity and stringency of the system can be evaluated on the basis of overall reduction targets and the annual cap trajectory while the control effect of the system can be estimated based on the price of the emission allowance. Table 20 presents a summary of 18 emission trading systems currently on operation in a descending order according to the overall GHG emissions of a given region. The original representation for the annual cap decline varies considerably due to which it has been recalculated in the table and unified to match the representation of the EU ETS.

Table 20 Main parameters of the 18 operational emission trading systems as of January 2019. (International Carbon Action Partnership, 2019; The Regional Greenhouse Gas Initiative, 2019; Bank of Finland, 2019; European Environment Agency, 2019a).

Name of the ETS	Operational since	Overall GHG emissions	ETS coverage	Price €/t-CO_2	Overall reduction targets (base year)	Annual ETS cap trajectory	Buildings included?	Type	Point of regulation
EU ETS	2005	4 440 *(2016)*	45 %	22,8 *01/19*	2020: -20 % (1990) 2030: -40 % (1990) 2050: at least -80 %	2013-2020: -1,74 % 2020-2030: 2,2 %	No	Mandatory	Downstream
Korea Emissions Trading Scheme	2015	690,6 *(2014)*	68 %	17,9 *01/18*	2020: -30 % (BAU) 2030: -37 % (BAU), or -22 % (2012)	2015-2017: -2,0 % 2018: -2,3 % 2019-2020: N/A	Facilities > 25 kt-CO_2	Mandatory + volunt. opt-in	Downstream
Regional Greenhouse Gas Initiative (RGGI)	2009	446,0 *(2012)*	20 %	5,1 *12/18*	2020: -50 % (2005) 2030: -30 % (2020) *Latter target not yet officially adopted*	2015-2020: -2,5 % 2021-2030: -3,0 %	No	Mandatory	Downstream
California Cap-and-Trade Program	2013	429,4 *(2016)*	85 %	13,1 *01/19*	2020: 0 % (1990) 2030: -40 % (1990) 2050: -80 % (1990)	2015-2020: -3,3 % 2021-2030: -5,1 %	Yes	Mandatory	Mixed
Kazakhstan Emissions Trading Scheme	2013 *suspended 2016-2017)*	298,1 *(2015)*	50 %	N/A	2020: -5 % (1990) 2030: -15 % (1990)	2018-2020: 0,0 % *(results the -5 % reduction)*	No	Mandatory	Downstream
New Zealand Emissions Trading Scheme	2008	80,2 *(2015)*	52 %	13,4 *02/18*	2020: -5 % (1990) 2030: -11 % (1990) 2050: -50 % (1990)	The system is not capped	Yes	Mandatory + volunt. opt-in	Upstream + possibility to opt-in downstream
Quebec Cap-and-Trade System	2013	77,3 *(2016)*	85 %	13,1 *01/19*	2020: -20 % (1990) 2030: -37,5 % (1990) 2050: -80–95% (1990)	2015-2020: -3,5 % 2021-2029: -2,5 %	Yes	Mandatory	Mixed
Tokyo Cap-and-Trade Program	2010	65,8 *(2015)*	20 %	N/A	2020: -25 % (2000) 2030: -30 % (2000)	2010-2014: -1,3 % 2015-2019: -2,1%	Facilities consuming >16 GWh	Mandatory	Downstream
Swiss ETS	2008	48,14 *(2015)*	11 %	6,8 *10/17*	2020: -20 % (1990) 2025: -35 % (1990) 2030: -50 % (1990)	2013-2020: -1,74 %	No	Mandatory + volunt. opt-in	Downstream
Saitama Target Setting Emissions Trading System	2011	37,2 *(2015)*	18 %	N/A	2020: -21 % (2005)	2011-2014: -1,3 % 2015-2019: -1,6 %	Facilities consuming >16 GWh	Mandatory	Downstream
Chinese pilot systems: *Shenzhen, Guangdong, Fujian Shanghai Tianjin, Beijing Hubei Chongqing*	2013-2014	Total: 2 350 Average: 290 *(2010-2014)*	40 % to 60 %	1,1 to 7,0 *01/18*	**Shenzen**: 2020: carbon intensity -45 % (2005) 2022: peak emissions **Others**: 2020: carbon intensity ~ -20 (2015)	N/A	**Shenzhen**: >20000 m^2 public, >10000 m^2 government **Others:** no	Mandatory	Power sector: upstream Other sectors: downstream

The building sector has been fully included in emission trading in three systems: California Cap-and-Trade Program, Quebec Cap-and-Trade System and New Zealand Emissions Trading Scheme. Four systems in Asia; Korea Emissions Trading Scheme, Tokyo Cap-and-Trade Program, Saitama Target Setting Emissions Trading System and Shenzhen pilot system; have decided to partially include the buildings sector into their systems. The systems in the latter listing have all excluded the smallest buildings with varying thresholds based on the total emissions, energy consumption and the floor area of a given facility. In the remaining 10 systems the building sector is not included in emission trading. (International Carbon Action Partnership, 2019)

Systems wherein the building sector is not included in emission trading are excluded from further analysis off the bat. A closer look into the systems with partial inclusion reveals that in all of these systems the point of regulation is downstream. Such method does not provide any valuable information with regards to the inclusion of the heating sector in the EU ETS wherein upstream solution would be required. From the remaining systems, the market size of Quebec's and New Zealand's systems compare only a fraction to the EU ETS. Thus, further analysis of these systems is not considered relevant. Therefore, the only emission trading system with a relevance towards the inclusion of the heating sector in the EU ETS is the California Cap-and-Trade System. Chapter 5.2 below will provide further insights on this system.

5.2 California Cap-and-Trade Program

California's overall GHG emissions in 2016 were 430 Mt-CO_2-eqv of which some 85 % is covered by emission trading (International Carbon Action Partnership, 2019). Region's emissions are dominated by the transportation sector which accounts for 41 % of the total emissions. Transportation is followed by industrial (23 %), electricity (16 %), agriculture (8 %), residential (7 %) and commercial (5 %) sectors. California imports approximately third of its electricity from other states. These imports are also included in emission trading by border carbon adjustment – a unique feature not found in EU ETS. Figure 24 presents the sectoral distribution of California's GHG emissions in 2016. Carbon dioxide accounts for 83 % of these emissions, followed by CH_4 (9 %), N_2O (3 %) and other GHGs with high global warming potential (5 %). (Pauer, 2018; California Air Resources Board, 2019b)

Emission trading is an important tool in California's climate target to return its GHG emissions to 1990 levels by 2020. Beyond this milestone the reductions are expected to be -40 % by 2030 and -80 % by 2050. California Cap-and-Trade Program (California CAT) follows the same *cap and trade* principle as the EU ETS: overall amount of emission allowances is limited with annually decreasing cap while included entities carry out emission reductions and trade allowances. All major GHGs are considered: CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, NF_3 and other fluorinated gases. (International Carbon Action Partnership, 2019)

Albeit an important tool, California CAT plays less critical role in region's mitigation efforts compared to its European equivalent. Californian climate policy is dominated by sector-specific regulatory while emission trading ensures that the targets achieved. California CAT is estimated to drive only one-fifth of the mitigation measures while complementary measures account for the remaining 80 %. (Cullenward & Coghlan, 2016)

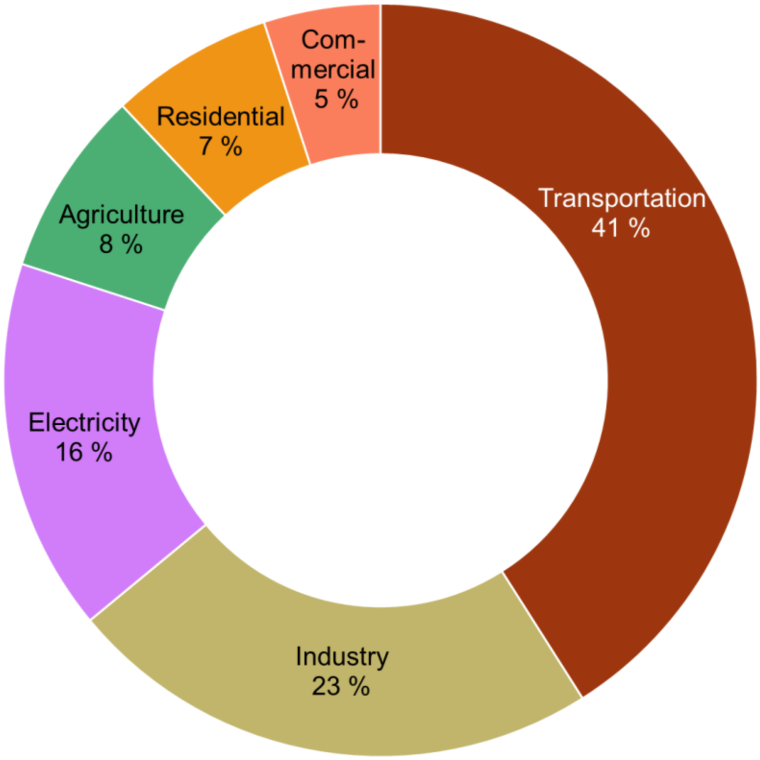

Figure 24 Sectoral distribution of California's GHG emissions in 2016 (California Air Resources Board, 2019b)

When the program commenced in January 2013 it covered large stationary industrial installations, other stationary combustion units, electricity producers and importers as well as CO_2 suppliers. The obligation to comply was imposed to entities emitting more than 25 kilotons of CO_2-eqv per annum. The sectoral coverage was extended at the beginning of the second compliance period with the decision to include distributors and suppliers of transportation fuels, natural gas and other fuels. The compliance threshold is identical for sectors included in the latter batch. (California Air Resources Board, 2015)

The program is divided into compliance periods: first period ran during 2013-2014, the second one from 2015 to 2017 and the third during 2018-2020. The system is foreseen to operate at least until 2030. In 2014 California CAT was officially linked with Quebec Cap-and-Trade System. Offsets can be used up to 8 per cent of entity's compliance obligation, albeit there are several geographical and sectoral limitations regarding their usage. Allowances are mostly allocated for free with differentiated allocation methodologies between the industry and other sectors. The allocation process is discussed further below in chapter 5.2.1. MRV process follows annual compliance cycle and is further discussed below in chapter 5.2.2. (California Air Resources Board, 2019a; International Carbon Action Partnership, 2019)

When the system was being designed, the designers wanted to avoid such oversupply of allowances as experienced with the EU ETS. Thus, a fixed price floor of was incorporated into the system. In practice, the price floor was implemented by setting a minimum clearing price of 10 \$/t-CO_2-eqv for the allowance auctions. The minimum price increases by 5 real percentage points every year. The price volatility has indeed been lower compared to the EU ETS. However, even with the price floor component, certain level of over-allocation was experienced in 2016 when the secondary prices temporary fell below the price floor. (Cullenward & Coghlan, 2016) In addition to price floor, the system has a price ceiling: if the price increases above the pre-defined threshold, supplementary allowances are offered in the following auction, increasing the supply. However, this instrument has not been triggered during the years of operation of the California CAT. (California Air Resource Board, 2019c)

5.2.1 Allocation Process

Both free allocation and auctioning are being used in the process of allocating the emission allowances. Allocation rules are different between the industry sectors and suppliers of fuels and distributors of electricity. Free allocation is the predominant method of allocation for the industrial sector and the number of allowances provided is based on sector-specific benchmarks. A brief comparison of benchmark values between the EU ETS and California CAT reveals European benchmarks to be somewhat tighter for most sectors. (California Air Resources Board, 2011a)

For most sectors within the California CAT the benchmark value is 90 % of the production-weighted average. Within certain sectors where the production-based average is not applicable, benchmarks are determined according to the most carbon-efficient installations. California CAT recognizes sectors that are exposed to the risk of carbon leakage and provides additional allowances to these sectors. More detailed description on constructing the benchmarks in general terms is provided in chapter 3.3.1. (California Air Resources Board, 2011a)

Distributors of electricity and suppliers of natural gas face similar allocation process: both sectors are provided with free allocation. According to the regulation, the value of the allowances can only be used to benefit the ratepayers and to reduce GHG emissions. (Woo, et al., 2017; California Air Resources Board, 2018) Transportation – the single most emitting sector within the region – does not receive any free allocation. This means that the cost of carbon in fully passed on to the end users. (Environmental Defense Fund, 2018)

Suppliers of transportation fuels must acquire allowances through quarterly held auctions. California CAT arranges auctions jointly together with the linked Quebec Cap-and-Trade System. Contrary to the EU ETS having no price management tool, California CAT has an *annual auction reserve price* – annually increasing threshold below which no bids are accepted. This means that the number of provided allowances is flexible according the supply and demand while the minimum price has been fixed. The threshold for 2019 is 15,62 $ which equals to 13,65 € as of February 2019. Auctions are held in online platform and they follow the same single-round, sealed-bid format as the EU ETS. More detailed description on the practicalities of such auction is provided in chapter 3.3.2. (California Air Resources Board, 2019d; Bank of Finland, 2019)

5.2.2 Monitoring, Reporting and Verification

California Air Resources Board (CARB) is the competent authority responsible of the oversight of the California CAT. Since the 2009 CARB has required compulsory reporting of GHG emissions from entities emitting over 10 kilotons of CO_2-eqv. Electricity generators and importers, fuel suppliers, carbon dioxide producers as well as industrial installations that produce GHGs over 25 kilotons of CO_2-eqv per annum must verify their emissions by an accredited third party and participate in California Cap-and-Trade program. (Environmental Defense Fund, 2018)

The point of regulation depends on the sector and is a mixture between upstream and downstream regulation. Industrial operators, electricity producers and carbon dioxide producers must report their GHG emissions on downstream basis. The compliance obligation also applies to the importers of electricity, an important feature preventing carbon leakage and resource shuffling. Suppliers of fuels carry out reporting on upstream basis and base their emissions on the assumption that the fuels they deliver will later be fully oxidized. (California Air Resources Board, 2017)

The compliance cycle is rather similar compared to the EU ETS. An essential document concerning the MRV requirements is the greenhouse gas report that all entities must fill in annually. The report must contain the name and location of the company, time period covered by the report and GHG-specific emissions. The report must be submitted latest by March 31st on the following year. (California Air Resources Board, 2011b)

The MRV regulation requires 5 % measurement accuracy for all the parameters used for calculations in the GHG report. The regulation imposes provisions for situations wherein certain measurement data is missing. If data is missing but the capture rate is above 90 %, the reporter should replace the missing data by using the 90th percentile from the data set of previous 3 years. Should the data capture rate be between 80 % and 90 %, the single highest value from the data set of previous 3 years must be used. If the capture rate is below 80 %, the highest value from all years must be used. (California Air Resources Board, 2019e) Entities not complying with the MRV regulation are deemed to surrender the missing allowances times four during the following compliance cycle (Hingne, 2018).

6 Discussion

European heating sector is dominated by small, property-specific natural gas and oil boilers situated in residential and service sector buildings. These boilers fall below the 20-megawatt threshold and thus, are excluded from the EU ETS. Instead, the sector is governed by ESD which imposes countries to implement national policies in order to meet the emission reduction targets. Certain European-wide assistance is provided by regulations governing the energy efficiency of buildings and minimum rates for heating fuels. The most recent studies unequivocally indicate significant energy efficiency improvements within new constructions. However, slow construction and renovation rates are together putting the brake on the development and the current trend will not be sufficient to meet the reduction targets. Expanding the scope of the EU ETS could change the course and unleash the existing potential of cost-effective GHG emission reductions of the building sector.

A comparison of fuel taxation between the member states of the European Union was carried out. The analysis discovered notable contrast between the countries, both with regards to the underlying principles as well as with the overall rates. Certain countries have implemented a carbon component into their fuel taxation – in accordance with Commissions rejected proposal. Thus, these countries have already taken the first step towards the inclusion of the heating sector in the EU ETS. On the other hand, some countries show no interest of doing so and a few have not even implemented the minimum tax rates set by the taxation directive into their national legislation. Asymmetric levies reflect the differences in the expected reactions if the inclusion of the heating sector in the EU ETS will be officially proposed. Absence of correlation between the tax levies and the prosperity of the country was slightly surprising. More research is needed to study the national politics behind these figures and to determine the political playing field.

Another research question was to evaluate that on which sector the reduction measures would actually be implemented in the event of inclusion of the heating sector in the EU ETS. MACC is an instrument used for the purpose of estimating the differences in sector's marginal abatement costs. Although a detailed Europe-specific MACC which includes the whole abatement potential was not found, several curves with similar characteristics were discovered. The curves unanimously put the residential sector measures into the leftmost side of the figure. However, Europe-specific MACC would allow even better estimation of the mitigation potential and is a question of more research.

A significant proportion of building sector's reduction measures are not only cost-effective but also cost-negative. A decade-old estimate of country-specific abatement potential in the building sector was found and it revealed that nearly all countries of the EU have significant amounts of potential with a negative cost. The existence of measures with negative cost could be argued with the inability to recognize the long-term viability beyond excessive upfront payments. Should the ETS work efficiency, the cost of carbon is equal everywhere within the scope of the system. However, current policies disincentive the ETS sectors to carry out any kinds reduction methods in the heating sector, despite the MAC is significantly lower than the current price of carbon. The coexistence of negative abatement costs within the building sector and positive cost of carbon on the ETS sector is a proof of ineffective markets which is far from minimizing the overall cost of emission reductions.

Expanding the EU ETS would be highly visible event raising awareness of the negative costs. Certain studies suggest that increases in the energy taxes trigger stronger demand responses compared to identical increases in the market price. This implies increased involvement by the residential sector itself in the heating sector will be included in the EU ETS. In terms of overall emission reduction, it is irrelevant whether the reduction measures are initiated by the current ETS sectors or by the residential sector itself. One of the main advantages of emission trading is that the overall emissions are effectively reduced and the market is left free to decide the targeting of the measures.

After researching the other 18 emission trading systems on operation around the World, the California Cap-and-Trade was identified to be the sole comparable system. Both the EU ETS and California CAT appear as successful examples of emission trading schemes and are important tools in the GHG emission mitigation efforts of the regions. However, drawing a strong equals sign between these systems can be misleading. EU ETS is a cornerstone in the European climate policy while California's mitigation efforts are dominated by sectoral regulatory. The role of market-based mechanisms has drifted to the offside and currently California CAT works as a tailboard, ensuring that sector-specific targets are realized. Californian system does demonstrate that nearly a full coverage of all economic sectors is possible and proves that a mixture of downstream and upstream regulation is feasible without compromising the environmental integrity.

7 Conclusions

International climate policy has evolved considerably since the first baby steps were taken in the 1970s. Adopting the Kyoto Protocol in 1997 resulted to the creation of the European Union emission trading system – a centerpiece in European climate policy. Credibility of the system has rightly been questioned due to the difficulties experienced throughout its years of operation. Accepting certain structural modifications into the system, such as the market stability reserve, has fixed earlier mistakes regarding the over-allocation and inability to respond to economic shocks. Furthermore, the reserve is expected to provide resilience from future shocks, increasing predictability and placing the credibility to an adequate level.

Due to the necessity to revise the structural weaknesses of the system, attention has distracted from the initial vision of gradual expansion of the scope of the system. Heating sector accounts for nearly 15 % of EU's overall GHG emissions and provides potential alternative to be included in emission trading due to its large unleashed potential of cost-effective emission reductions. Emissions from the heating sector are mostly produced by burning natural gas and gasoil in small, property-specific boilers in residential and service sector buildings. These emissions could be reduced primarily by energy efficiency measures, such as insulation retrofit. European Commission has already addressed the issue with a recast of the energy performance of buildings directive. The initiative has indeed succeeded to significantly improve the energy efficiency of new constructions. However, the European building stock is dominated by old and energy inefficient buildings whereas the slow renewal rate means that the status quo is not sufficient to meet the future emission targets.

Large share of building sector's reduction potential is not only cost-effective but also cost-negative, focusing in particular to the residential sector. The prominent existence of negative MACs can be seen as a sign of inefficient markets which fails to minimize the overall abatement cost. In a well-functioning emission trading system the price of carbon should be the same everywhere within the scope of the system. However, the current policies distinguish ETS sectors from the building sector and provides no incentive for ETS sectors to exploit the cheap and cost-negative abatement potential. Inclusion of the heating sector is a potential solution to the issue. However, significant differences between counties' fuel taxation indicate that adopting such measure will be politically challenging

EU ETS currently implements monitoring, reporting and verification towards the compliance on a downstream basis. Such method would not be feasible in the event of including over 100 million boiler units of the heating sector in the EU ETS and the governance should therefore be expanded to fuel supplier level. California Cap-and-Trade Program provides a case study example of successful implementation of upstream regulation and verifies that such method is feasible.

References

2003/87/EC, 2003. Directive 2003/87/EC of the European Parliament and of the council establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. *Official Journal of the European Union,* pp. 32-46.

2003/96/EC, 2003. Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity. *Official Journal of the European Union,* pp. 51-70.

2007/C/306/01, 2007. *Treaty of Lisbon - Amending the Treaty on European Union ans the Treaty Establishing the European Community (2007/C 306/01).* Lisbon, Portugal: Official Journal of the European Union.

2010/31/EU, 2010. Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings. *Official Journal of the European Union*, pp. 13-35.

2012/27/EU, 2012. DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency. *Official -journal of the European Union*, pp. 1-56.

2018/410/EU, 2018. DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments and Decision (EU) 2015/1814. *Official Journal of the European Union,* pp. 3-27.

2018/842/EU, 2018. REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030. *Official Journal of the European Union,* pp. 26-42.

2018/844/EU, 2018. DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU. *Official Journal of the European Union*, pp. 75-91.

Artola, et al., 2016. *Boosting Building Renovation; What Potential and Value for Europa - Study for the ITRE Committee,* s.l.: Directorate General for Internal Policies.

Babonneau, F., Haurie, A. & Vielle, M., 2018. Welfare implications of EU Effort Sharing Decision and possible impact of a hard Brexit. *Energy Economics,* Volume 74, pp. 470-489.

Bank of Finland, 2019. *Exchange rates.* [Online] Available at: https://www.suomenpankki.fi/en/Statistics/exchange-rates/ [Accessed 14. 1. 2019].

Borghesi, S. & Flori, A., 2018. EU ETS facets in the net: Structure and evolution of the EU ETS network. *Energy Economics,* Volume 75, pp. 602-635.

Boyce, J., 2018. Carbon pricing; Effectiveness and Equity. *Ecological Economiscs,* Volume 150, pp. 52-61.

Buildings Performance Institute Europe, ei pvm *97% OF BUILDINGS IN THE EU NEED TO BE UPGRADED,* Brussels, Belgium: Buildings Performance Institute Europe.

Burke, P. & Abayasekara, A., 2017. The price elasticity of electricity demand in the United States: A three-dimensional analysis, Canberra, Australia: Australian National University.

Böhringer, C., Rosendahl, K. E. & Storrøstem, H. B., 2017. Robust policies to mitigate carbon leakage. *Journal of Public Economics,* Volume 149, pp. 35-46.

California Air Resources Board, 2011. *Appendix B: Development of Product Benchmarks for Allowance Allocation,* s.l.: California Air Resources Board.

California Air Resources Board, 2015. *Overview of ARB Emissions Trading Program,* Sacramento, California: California Environmental Protection Agency.

California Air Resources Board, 2018. *Electrical Distribution Utility and Natural Gas Supplier Use of Allocated Allowance Value.* [Online] Available at: https://www.arb.ca.gov/cc/capandtrade/allowanceallocation/edu-ng-allowance-value.htm
[Accessed 5. 2. 2019].

California Air Resources Board, 2019a. *Cap-and-Trade Program.* [Online] Available at: https://www.arb.ca.gov/cc/capandtrade/capandtrade.htm
[Accessed 3. 2. 2019].

California Air Resources Board, 2019b. *California Greenhouse Gas Emission Inventory - 2018 Edition.* [Online] Available at: https://www.arb.ca.gov/cc/inventory/data/data.htm
[Accessed 4. 2. 2019].

California Air Resources Board, 2019c. *Reserve Sale Information.* [Online] Available at: https://www.arb.ca.gov/cc/capandtrade/reservesale/reservesale.htm
[Accessed 5. 2. 2019].

California Air Resources Board, 2019d. *Auction Notice: California Cap-and-Trade Program and Québec Cap-and-Trade System Joint Auction of Greenhouse Gas Allowances On February 20, 2019,* Sacramento, California: California Air Resources Board.

Capros, P. & Mantzos, L., 2000. *The Economic Effects of EU-Wide Industry-Level Emission Trading to Reduce Greenhouse Gases,* Athens, Greece: Institute of Communication and Computer Systems of National Technical University of Athens.

Carbon Tracker Initiative, 2018. *Media Release, August 21,* London, United Kingdom: Carbon Tracker Initiative.

Chaton, C., Creti, A. & Sanin, M.-E., 2018. Assessing the implementation of the Market Stability Reserve. *Energy Policy,* 118(0301-4215), pp. 642-654.

Connolly, D. et al., 2013. *Heat Roadmap Europe 2,* Aalborg, Denmark: Aalborg University.

Cullenward, D. & Coghlan, A., 2016. Structural oversupply and credibility in California's carbon market. *The Electricity Journal,* 29(5), pp. 7-14.

Edenhofer, O. et al., 2017. *Decarbonization and EU ETS Reform: Introducing a price floor to drive low-carbon investments,* Berlin, Germany: Mercator Research Institute on Global Commons and Climate Change (MCC) gemeinnutzige GmbH.

Ellerman, D., Convery, F. & Perthuis, C., 2010. *Pricing Carbon - The European Union Emissions Trading Scheme.* 2nd toim. Cambridge, the United Kingdom: Cambridge University Press.

Ellerman, D., Marcantonini, C. & Zaklan, A., 2016. The European Union Emissions Trading System: Ten Years and Countring. *Review of Environmental Economics and Policy,* 10(1), pp. 89-107.

Environmental Defense Fund, 2018. *California's cap-and-trade program step by step,* Sacramento, California: Environmental Defense Fund.

EU No 600/2012, 2012. *COMMISSION REGULATION (EU) No 600/2012 of 21 June 2012 on the verification of greenhouse gas emission reports and tonne-kilometre reports and the accreditation of verifiers pursuant to Directive 2003/87/EC of the European Parliament and of the Council.* Brussels, Belgium: Official Journal of the European Union.

EU No 601/2012, 2012. *COMMISSION REGULATION (EU) No 601/2012 of 21 June 2012 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council.* Brussels, Belgium: Official Journal of the European Union.

European Commission, 1998. *Climate Change - Towards an EU Post-Kyoto Strategy, COM(1998) 353 final,* Brussels: Office for Official Publications of the European Communities.

European Commission, 1999. *Preparing for Implementation of the Kyoto Protocol, COM(1999) 230,* s.l.: s.n.

European Commission, 2000. *Green Paper on greenhouse gas emissions trading within the European Union,* Brussels, Belgium: s.n.

European Commission, 2004. *Kyoto Protocol,* Brussels, Belgium: European Commission Press Release Database.

European Commission, 2011. *Revision of the Energy Taxation Directive – Questions and Answers,* Brussels, Belgium: European Commission.

European Commission, 2015. *EU ETS Handbook,* Brussels, Belgium: European Union.

European Commission, 2016. *Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 2: Assessment of the technologies for the year 2012,* Brussels, Belgium: European Commissions.

European Commission, 2017. *Guidance Document - The Monitoring and Reporting Regulation – General guidance for installations,* Brussels, Belgium: European Commission.

European Commission, 2018a. *EU Emissions Trading System (EU ETS).* [Online] Available at: https://ec.europa.eu/clima/policies/ets_en [Accessed 28 9 2018].

European Commission, 2018b. *Auctioning.* [Online] Available at: https://ec.europa.eu/clima/policies/ets/auctioning_en [Accessed 6. 11. 2018].

European Commission, 2018c. *Guidance Document - The Monitoring and Reporting Regulation – General guidance for Aircraft Operators,* Brussels, Belgium: European Commission.

European Commission, 2018d. *EU Buildings Database.* [Online] Available at: https://ec.europa.eu/energy/en/eu-buildings-database [Accessed 14. 12. 2018].

European Commission, 2019. *Taxes in Europe Database v3.* [Online] Available at: http://ec.europa.eu/taxation_customs/tedb/splSearchForm.html [Accessed 10. 1. 2019].

European Council, 2018. *Infographic - Non-ETS emissions by sector.* [Online] Available at: https://www.consilium.europa.eu/en/infographics/non-ets-emissions-by-sector/
[Accessed 14. 11. 2018].

European Energy Exchange, 2019. *European Emission Allowances.* [Online] Available at: https://www.eex.com/en/market-data/environmental-markets/spot-market/european-emission-allowances
[Accessed 10. 1. 2019].

European Environment Agency, 2016. *Trends and projections in Europe 2016 - Tracking progress towards Europe's climate and energy targets,* Copenhagen, Denmark: European Environment Agency.

European Environment Agency, 2018a. *Data and maps, Search: EUA.* [Online] Available at: https://www.eea.europa.eu/data-and-maps/figures#c0=15&c5=&c15=all&b_start=0&c8=eua
[Accessed 17. 10. 2018].

European Environment Agency, 2018b. *Trends and projections in the EU ETS in 2018 - The EU Emissions Trading System in numbers,* Copenhagen, Denmark: European Environment Agency.

European Environment Agency, 2018c. *Trends and projections in Europe 2018 - Tracking progress towards Europe's climate and energy targets,* Brussels, Belgium: European Environment Agency.

European Environment Agency, 2019a. *EEA greenhouse gas - data viewer.* [Online] Available at: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
[Accessed 13. 11. 2018].

European Environment Agency, 2019b. *Greenhouse gas emissions under the Effort Sharing Decision (ESD).* [Online] Available at: https://www.eea.europa.eu/data-and-maps/data/esd-1 [Accessed 13. 11. 2018].

European Environment Agency, 2019c. *EU Emissions Trading System (ETS) data viewer.* [Online]
Available at: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1
[Accessed 3. 2. 2019].

Eurostat, 2017. *Energy balance sheets - 2015 data - 2017 edition,* Luxembourg: Publications Office of the European Union.

Eurostat, 2018a. *Electricity production, consumption and market overview.* [Online] Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview#Electricity_generation
[Accessed 11. 16. 2018].

Eurostat, 2018b. *GDP per capita in PPS.* [Online] Available at: https://ec.europa.eu/eurostat/web/products-datasets/-/tec00114 [Accessed 5. 12. 2018].

Fan, Y., Jia, J.-J., Wang, X. & Xu, J.-H., 2017. What policy adjustments in the EU ETS truly affected the carbon prices?. *Energy Policy,* Volume 103, pp. 145-164.

Fokaides, P., Polycarpou, K. & Kalogirou, S., 2017. The impact of the implementation of the European Energy Performance of Buildings Directive on the European building stock: The case of the Cyprus Land Development Corporation. *Energy Policy,* Volume 111, pp. 1-8.

Forster, D. et al., 2012. *Next phase of the European Climate Change Programme: Analysis of Member States actions to implement the Effort Sharing Decision and options for further community-wide measures – Appendix 1: Greenhouse gas emissions projections, emissions limits and abatement potential in ESD sectors,* Didcot, United Kingdom: AEA Technology.

GreenStream, 2015. *Inclusion of the heating sector in the EU ETS,* s.l.: GreenStream Network Ltd..

Haites, E. & Yamin, F., 2004. Overview of the Kyoto Mechanisms. *International Review for Environmental Strategies,* 5(1), pp. 199-216.

Hasselknippe, H. & Christiansen, A., 2003. *Energy Taxation in Europe: Current Status - Drivers and Barriers - Future Prospects,* Laysaker, Norway: Fridtjof Nansens Institutt.

Heat Roadmap Europe, 2017. *Heating and Cooling Energy Demands.* [Online] Available at: https://heatroadmap.eu/heating-and-cooling-energy-demand-profiles/ [Accessed 15. 11. 2018].

Hepburn, C., Neuhoff, K. & Acworth, W., 2016. The economics of the EU ETS market stability reserve. *Journal of Environmental Economics and Management,* Volume 80, pp. 1-5.

Intergovernmental Panel on Climate Change, 2018. *Intergovernmental Panel on Climate Change - Organization.* [Online] Available at: http://www.ipcc.ch/organization/organization.shtml [Accessed 18. 9. 2018].

International Carbon Action Partnership, 2019. *ICAP ETS Map.* [Online] Available at: https://icapcarbonaction.com/en/ets-map [Accessed 14. 1. 2019].

Kari, S. et al., 2018. *Common or own goals: Reforming the financing of the European Union,* Helsinki, Finland: Valtionneuvoston kanslia.

Kesicki, F., 2011. Marginal abatement cost curves for policy making – expert-based vs. model-derived curves, London, United Kingdom: University College London.

Koch, N., Fuss, S., Godefroy, G. & Edenhofer, O., 2014. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything? - New evidence. *Energy Policy,* Volume 73, pp. 676-685.

Marklund, P. & Samakovlis, E., 2006. What is driving the EU burden-sharing agreement: Efficiency or equity?. *Journal of Environmental Management,* October, 85(2), pp. 317-329.

Martinopoulos, G., Papakostas, K. & Papadopoulos, A., 2018. A comparative review of heating systems in EU countries, based on efficiency and fuel cost. *Renewable and Sustainable Energy Reviews,* Volume 90, pp. 687-699.

McKinsey&Company, 2010. Impact of the financial crisis on carbon economics - Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve, McKinsey&Company.

Mosby, A. & Knell, S., 2018. *Climate and Carbon Insight,* London, United Kingdon: IHS Markit.

Nykänen, J. et al., 2006. *Päästökauppa ja ympäristöhyödykkeiden markkinat (Emissions trading and environmental commodity markets).* Helsinki: Edita Publishing Oy.

OECD, 2018. Taxing Energy Use 2018, Paris, France: OECD Publishing.

OECD & IEA, 2001. *The Commitment period Reserve,* Paris, France: OECD Environment Directorate and International Energy Agency.

Paroussos, L., Fragkos, P., Capros, P. & Fragkiadakis, K., 2015. Assessment of carbon leakage through the industry channel: The EU perspective. *Technological Forecasting and Social Change,* 90(A), pp. 204-219.

Pauer, S., 2018. Including electricity imports in California's cap-and-trade program: A case study of a border carbon adjustment in practice. *The Electricity Journal,* 31(10), pp. 39-45.

Perthuis, C. & Trotignon, R., 2014. Governance of CO2 markets: Lessons from the EU ETS. *Energy Policy,* Volume 75, pp. 100-106.

Phylipsen, G., Bode, J. & Blok, K., 1998. A triptych sectoral approach to burden differentation: GHG emissions in the European bubble. *Energy Policy,* 26(12), pp. 929-943.

Refinitiv, 2018. *Will high European carbon prices last?.* [Online] Available at: https://www.refinitiv.com/perspectives/market-insights/will-high-european-carbon-prices-last/
[Accessed 20. 12. 2018].

Sandbag, 2019. *EUA price.* [Online] Available at: https://sandbag.org.uk/carbon-price-viewer/
[Accessed 1. 2. 2019].

Schlegel, I., 2014. The Future of European Energy Taxes in the Context of Environmental Policy Instruments. *Carbon & Climate Law Review,* 8(2), pp. 115-124.

Schleich, J., Rogge, K. & Betz, R., 2009. Incentives for energy efficiency in the EU Emissions Trading Scheme. *Energy Efficiency,* 2(1), pp. 37-67.

Sesana, M. & Salvalai, G., 2018. A review on Building Renovation Passport: Potentialities and barriers on current initiatives. *Energy and Buildings,* Volume 173, pp. 195-205.

Soliman, A. & Nasir, M., 2018. Association between the energy and emission prices: An analysis of EU emission trading system. *Resources Policy.*

Spencer, T; Pierfederici, R; Sartor, O; Berghmans, N; Samadi, S; Fischedick, M; Knoop, K; Pye, S; Criqui, P; Mathy, S; Capros, P; Fragkos, P; Bukowski, M; Sniegocki, A; Virdis, M; Gaeta, M; Pollier, K; Cassisa, C. Tracking sectoral progress in the deep decarbonisation of energy systems in Europe. *Energy Policy*, Volume 110, pp. 509-517.

Statistic Finland, 2018a. *Concepts - District heat.* [Online] Available at: https://www.stat.fi/meta/kas/kl_en.html [Accessed 19. 11. 2018].

Statistics Finland, 2018b. *Polttoaineluokitus 2018 / Fuel classification.* [Online] Available at: https://www.stat.fi/tup/khkinv/khkaasut_polttoaineluokitus.html [Accessed 29. 10. 2018].

The Regional Greenhouse Gas Initiative, 2019. *Auction Results.* [Online] Available at: https://www.rggi.org/auctions/auction-results [Accessed 14. 1. 2019].

The Royal Society, 2005. *A Guide to Facts and Fictions About Climate Change,* London: The Royal Society.

Twidale, S., 2018. Berenberg doubles its EU carbon price forecasts for 2019/2020. *Reuters*, 17. 10..

United Nations, 1972. *Report of the United Nations Conference on the Human Environment,* Stockholm: United Nations Publication.

United Nations, 1992. *United Nations Framework Convention on Climate Change,* Rio de Janeiro: s.n.

United Nations, 1998. *Kyoto Protocol to the United Nations Framework Convention on Climate Change,* Kyoto: United Nations.

United Nations, 2008. *United Nations Framework Convention on Climate Change - Kyoto Prorocol Reference Manual on Accounting of Emissions and Assigned Amount,* Bonn, Germany: Climate Change Secretariant (UNFCCC).

United Nations, 2018a. *United Nations Framework Convection on Climate Change - Parties & Observers.* [Online] Available at: https://unfccc.int/parties-observers [Accessed 9. 18. 2018].

United Nations, 2018b. *United Nations Framework Convention of Climate Change - List of Parties to the Convention.* [Online] Available at: https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states
[Accessed 18. 9. 2018].

United Nations, 2018c. *United Nation Framework Convention on Climate Change - GHG Data.* [Online]

Available at: http://di.unfccc.int/time_series [Accessed 19. 9. 2018].

United Nations, 2018d. *United Nations Framework Convention on Climate Change - FOCUS: Mitigation - Reporting on nstional implementation and MRV.* [Online] Available at: GHG Data - [Accessed 19. 9. 2018].

United Nations, 2018e. *United Nations Framework Convention on Climate Change - The Kyoto Protocol - Status of Ratification.* [Online] Available at: https://unfccc.int/process/the-kyoto-protocol/status-of-ratification [Accessed 19. 9. 2018].

United Nations, 2018f. *United Nations Treaty Collection - Kyoto Protocol to the United Nations Framework Convention on Climate Change.* [Online] Available at: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en
[Accessed 19. 9. 2018].

United Nations, 2018g. *United Nations Framework Convention on Climate Change - Mechanisms under the Kyoto Protocol.* [Online] Available at: https://unfccc.int/process/the-kyoto-protocol/mechanisms/ [Accessed 19. 9. 2018].

United Nations, 2018h. *United Nations Framework Convention on Climate Change - Emissions Trading.* [Online] Available at: https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading [Accessed 19. 9. 2018].

United Nations, 2018i. *United Nations Framework Convention on Climate Change - Registry Systems under the Kyoto Protocol.* [Online] Available at: https://unfccc.int/process/the-kyoto-protocol/registry-systems [Accessed 19. 9. 2018].

United Nations, 2018j. *United Nations Framework Convention on Climate Change - International Transaction Log.* [Online] Available at: https://unfccc.int/process/the-kyoto-protocol/registry-systems/international-transaction-log
[Accessed 19. 9. 2018].

United Nations, 2019. *Sustainable Development Knowledge Platform.* [Online] Available at: https://sustainabledevelopment.un.org/milestones/humanenvironment [Accessed 18. 9. 2018].

U.S. Energy Information Administration, 2014. Price Elasticities for Energy Use in Buildings of the United States, Washington DC, United States: U.S. Department of Energy.

Valtonen, A., 2013. *Pallo Neuvottelijoilla (The ball is in negotiators court).* Helsinki: Ympäristöministeriö.

Werner, S., 2017. International review of district heating and cooling. *Energy,* Volume 137, pp. 617-631.

Woo, C. et al., 2017. Does California's CO2 price affect wholesale electricity prices in the Western U.S.A.?. *Energy Policy,* Volume 110, pp. 9-19.

World Bank, 2018a. *World Bank Open Data - Total greenhouse gas emissions.* [Online] Available at: https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE [Accessed 19. 9. 2018].

World Bank, 2018b. *Population, total.* [Online] Available at: https://data.worldbank.org/indicator/SP.POP.TOTL [Accessed 4. 12. 2018].

World Meteorological Organization, 2009. *A History of Climate Activities, Bulletin nro: Vol 58 (3).* [Online] Available at: https://public.wmo.int/en/bulletin/history-climate-activities [Accessed 18. 9. 2018].

Yamin, F., 2005. *Climate change and carbon markets: a handbook of emission reduction mechanisms.* London: Routledge.